REAL OPTIONS IN VALUE APPROPRIATION:
THEORY AND EVIDENCE FROM PATENT STRATEGIES

BY

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DISSERTATION

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ABSTRACT

This dissertation proposes and shows that real options reasoning is important for understanding firms' value appropriation strategies in innovation. Despite a large body of research on real options for *value creation* in innovation, how real options reasoning can inform firms' decision-making in *value appropriation* strategies under uncertainty has received relatively little scrutiny. My dissertation seeks to address this gap in the literature by examining what drives firms to purchase real options as mechanisms to preserve flexibility in their commitment decisions in patenting strategies.

In my first empirical study (Chapter 2), I seek to examine the patent-secrecy choice as an exemplar of the value of such real options in appropriability strategies. As a primary hypothesis, I propose that the greater the risk of technology disclosure to rivals due to patenting, the more likely that firms purchase "secrecy options" to retain secrecy of inventions while attempting to patent them. I employ a difference-in-differences research design that leverages the American Inventors Protection Act, a quasi-exogenous change in U.S. patent law that resulted in faster disclosure of technologies pursuing patent protection, and show that firms were more likely to purchase secrecy options (by filing provisional patent applications) for patents affected by faster disclosure. Further, I find that this effect was quite large, and more pronounced for smaller firms and more novel technologies.

In my second empirical study (Chapter 3), I examine how firms strategically respond to the patent racing incentives created by a first-past-the-post principle of the patent system, and propose that they may do so by capitalizing on real options – represented by provisional applications – in the patenting process. I employ a difference-in-differences design that leverages

the transition of the U.S. patent system from a first-to-invent to a first-to-file system following the America Invents Act, and show that firms were more likely to file provisional applications (as real options on future patent applications) under a first-to-file system. Furthermore, I show that the magnitude of this effect depended on contingencies such as the firm's technological dominance, industry concentration and patent effectiveness.

In my third empirical study (Chapter 4), I examine firms' revealed preference to purchase real options in patent term extension by leveraging the Agreement on Trade Related Aspects of Intellectual Property Rights, which changed U.S. patent term from a 17-years-from-issuance to a 20-years-from-priority date term. I show that patent prosecution uncertainty increases the value of real options in patent term extension, consistent with real options theory. I find that a firm's purchase of real options is further related to industry differences, invention value, and the type of patent application (original versus continuing).

My dissertation contributes to the literature in real options theory as well as appropriability strategies by applying received theory to a new context. Implications for managers and policymakers are also discussed.

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Dedication

to my parents Sunyang and Kyunghee

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CHAPTER 1: INTRODUCTION

Appropriability – how do firms profit from innovation – is a fundamental research question in the technology strategy literature (e.g., Teece, 1986). A large body of research has examined different types of "appropriability mechanisms" whereby firms capture value from inventions, such as patents, secrecy, complementary assets, and lead time advantages (e.g., Cohen, Nelson, & Walsh, 2000; James, Leiblein, & Lu, 2013; Levin, Klevorick, Nelson, & Winter, 1987). Among these appropriability mechanisms, my dissertation focuses on strategies firms use to obtain the patent right on their inventions to protect them against rivals.

Patenting is costly (Sichelman & Graham, 2010). The pecuniary costs of patenting include the significant legal costs of conducting patent searches and drafting patent applications in addition to the straight-up fees which need to be paid to the patent office for filing, issuance, and maintenance. Furthermore, patenting entails significant opportunity costs. Drafting patent applications may divert inventors' time and attention from value-creating innovation activities. Making errors in drafting the right patent application (which are often only evident *ex post*) – e.g., delineating the right patent scope and claims – can be consequential. Patenting also requires giving up secrecy of inventions, which is an alternative appropriability mechanism that can potentially be more valuable in the long run. Both the pecuniary and opportunity costs of patenting represent significant irreversible commitments it requires.

At the same time, firms make patenting decisions under significant *ex ante* uncertainties – technological, commercial, and/or legal (e.g., Lemley & Shapiro, 2005; Pakes, 1986; Somaya, 2012) – which blurs the value of the patent right to be obtained. These uncertainties are in part evidenced by an empirical finding that 60% of U.S. patents were abandoned (i.e., not renewed) by patentees before expiry (Serrano, 2010). Another finding shows that the value distribution of patents is highly skewed (Harhoff, Scherer, & Vopel, 2003); only 10% of U.S. and German patents created 85% of the total value (Scherer & Harhoff, 2000).

In order to deal with the *ex ante* uncertainties in the value of the patent right as well as the costly commitments patenting requires, firms need to strategize their patenting decisions. This situation at issue is analogous to one in which firms contemplate irreversible investment decisions before substantial uncertainties are resolved. In this situation, real options theory provides important insights on how firms can preserve future decision rights, avoiding costly commitments to potentially risky choices (e.g., Dixit & Pindyck, 1994). The real options literature suggests that instead of making a full-blown commitment decision now, firms may purchase a real option, a right but not an obligation, to invest in the risky choice at a later time (i.e., to exercise the option). Thus, in my dissertation I posit that such real options reasoning can be valuable for understanding firms' patenting strategies.

Indeed, various topics in strategic management have been greatly informed by real options reasoning (Li et al., 2007; Trigeorgis & Reuer, 2017), such as market entry timing (e.g., Dixit & Pindyck, 1994; McDonald & Siegel, 1986), modes of entry (e.g., Kulatilaka & Perotti, 1998), and organizational forms (e.g., Folta & Miller, 2002; Kogut, 1991), and preemption versus cooperation tradeoffs (e.g., Smit & Trigeorgis, 2004; Teece, 1992). In the technology and innovation strategies space, prior research has shed light on how firms use real options reasoning to *create value* through innovation. Much of the empirical work has examined R&D strategies whereby current innovations open up opportunities for follow-on innovations in a technological space, taking a growth option and/or a "portfolio of options" perspective (e.g., Hurry, Miller, & Bowman, 1992; Mitchel & Hamilton, 1987; McGrath, 1997; McGrath & Nerkar, 2004).

However, despite the large body of research on real options for *value creation* in innovation, how real options reasoning can inform firms' decision-making in *value appropriation* strategies remains understudied. This gap in the literature is surprising because value appropriation strategies to capture profits from innovation are widely understood to be critical for firms (e.g., Lepak et al., 2007; Nordhaus, 1969; Teece, 1986; Scherer, 1965), while also being deployed under significant uncertainties regarding the technology and its commercial prospects. My dissertation seeks to address this gap in the literature by examining what drives firms to purchase real options to preserve flexibility in their commitment decisions in patenting strategies.

Three legal "shocks" to the U.S. patent system

Methodologically, I leverage three different changes in U.S. patent law to robustly deal with potential endogeneity concerns. In my first empirical study (Chapter 2), I use the American Inventors Protection Act (AIPA), which went into effect on November 29, 2000. The AIPA introduced an 18-month publication rule, whereby the U.S. patent system discloses information contained in a patent application to the public at 18 months from the priority date[1], regardless of whether a patent eventually issues or not. In the past legal framework, the U.S. patent system disclosed information contained in a patent application to the public at the time of patent issuance. Since an average patent application takes 2 to 3 years to issue a patent (e.g., Allison & Lemley, 2000; Popp et al., 2004), the AIPA resulted in substantially faster disclosure of technologies pursuing patent protection compared with the past legal framework in the U.S.

[1] Priority date is the earliest filing date, from which the patent applicant has a legal claim over the invention as the first inventor.

The AIPA was enacted in part to mitigate the problem of “submarine patenting” (Lemley & Moore, 2004), whereby patent applicants keep patents pending and secret until others in the industry make significant investments in the technology, in order to hold them up by bringing an infringement suit. The legislation was first introduced as a result of negotiations between the U.S. and Japan in August 1994 under the Global Agreement on Tariffs and Trade (GATT) (Schrader, 1997). Given that the AIPA was enacted in November 29, 1999, as part of a $390 billion omnibus spending bill (Ergenzinger, 2006), endogeneity concerns for the legislative change are mitigated to some extent.

In my second empirical study (Chapter 3), I use the America Invents Act (AIA), which went into effect on March 16, 2013. The AIA introduced a first-to-file patenting system to the U.S. and began to entitle only the first-inventor-who-files to a patent on an invention. In the past legal framework, the U.S. had a first-to-invent patenting system, which entitled the inventor who could prove that he/she was the first to invent an invention to the patent right. Thus, the AIA effectively increased the payoff of prompt filing of a patent.

The transition to a first-to-file system was aimed at making the patent system “globally competitive” by reducing a large volume of litigation and interference proceedings which determine who is the true inventor and thus has the patent right to the invention under a first-to-invent system (Hasford, 2017). The legislation was first proposed in 2005 and took years to be passed due to competing interests. The eventual passage of the legislation was possible due in part to the fact that strong advocates of a first-to-invent system had retired, passed away, or dropped their opposition to a first-to-file system (Wayne et al., 2012). This observation mitigates to some extent endogeneity concerns for the implementation of a first-to-file system in the U.S.

In my third empirical study (Chapter 4), I use the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS), which went into effect on June 8, 1995 through the Uruguay Round Agreements Act (URAA). Negotiated at the 1994 GATT, the TRIPS requires GATT members to adopt the patent term of 20 years from the priority date (Schrader, 1997). The U.S. agreed to become bound by the agreement by enacting the URAA. In the past legal framework, U.S. patent term was measured 17 years from the date of patent issuance. A new 20-year term incentivizes patent applicants to push for early issuance. Thus, the amendment of patent term was aimed at mitigating the problem of submarine patenting in addition to harmonizing the U.S. patent system with that of other countries. Both of these objectives were subsequently shared by an 18-month publication rule of the AIPA.

At the same time, patentees that filed during the interim period between the enactment and effective date of TRIPS were provided the two discrete choices between patent terms under the old or new rule. This transition rule implies that patentees could extend patent term by filing during the interim period relative to after the effective date of TRIPS.

Provisional patent applications

In my first two empirical studies (Chapter 2 and Chapter 3), I measure firms' purchase of real options by their use of provisional patent applications. Provisional applications were introduced in the U.S. by the URAA along with a new 20-year patent term. Provisional applications are informal applications (which do not require the drafting of formal claims) whereby firms establish a priority date for an invention and receive one year within which they must file a regular application to continue with securing the patent right (Migliorini, 2007). If a firm does not file a regular application within the one year, the earlier filed provisional application is effectively abandoned. Moreover, information contained in that provisional application is kept secret since the patent office does not examine provisional applications until after inventors file regular applications claiming priority to them. Therefore, I posit that provisional applications can be viewed as real options on patents (see Chapter 3). Alternatively, conditional on a firm starting the patenting process, provisional applications can be viewed as real options on secrecy (see Chapter 2), which is a mutually exclusive appropriability mechanism to patents (Graham & Somaya, 2004).

Table 1.1 compares the filing fees for regular and provisional applications during the sample period used in my dissertation. The filing fee for provisional applications is much lower than that for regular applications. The filing fees have changed over time, even within the respective sample period in the two chapters. While the minor changes in filing fees may raise concerns for my analyses examining firms' use of provisional applications relative to regular applications, these concerns are effectively addressed by using a difference-in-differences (DID) design[2] in the two chapters.

We have seen a steady increase in the use of provisional applications since their introduction. Figure 1.1 shows the number of provisional applications filed during the period 1998-2014. While the number of provisional applications filed in 1998 was 41,622, we see that 169,173 provisional applications were filed in 2014. The number has more than tripled over the period. Furthermore, the growth of provisional applications is also notable relative to the number of regular applications filed; we see that the ratio of provisional applications to regular applications has increased by 68.2% over the period (0.173 to 0.291).

[2] The changes in filing fees apply to both the treatment group of inventions pursuing only U.S. protection and the control group of inventions pursuing foreign protection. A DID design allows us to estimate the net effect by subtracting the effect in the control group from that in the treatment group, thus strictly controlling for the potential effect of filing fee changes.

Overview of the empirical studies in my dissertation

Despite a large body of research on real options for value creation in innovation, how firms use real options reasoning to strategize among alternative value appropriation choices under uncertainty has received relatively little scrutiny. In Chapter 2, I seek to examine the patent-secrecy choice as an exemplar of the value of such real options in appropriability strategies. As a primary hypothesis, I propose that the greater the risk of technology disclosure to rivals due to patenting, the more likely that firms purchase "secrecy options" to retain secrecy of inventions while attempting to patent them. I employ a difference-in-differences research design that leverages the American Inventors Protection Act, a quasi-exogenous change in U.S. patent law that resulted in faster disclosure of technologies pursuing patent protection, and show that firms were more likely to purchase secrecy options (by filing provisional patent applications) for patents affected by faster disclosure. Further, I find that this effect was quite large, and more pronounced for smaller firms and more novel technologies. These findings point to the promise of a new stream of research at the intersection of real options theory and appropriability strategies.

The patent system rewards inventors on a first-past-the-post principle, as epitomized by the first-to-file rule that entitles only the first-inventor-who-files to a patent on an invention. In Chapter 3, I examine how firms strategically respond to the patent racing incentives created by such a rule, and propose that they may do so by capitalizing on real options – represented by provisional applications – in the patenting process. I employ a difference-in-differences design that leverages the transition of the U.S. patent system from a first-to-invent to a first-to-file system following the America Invents Act, and show that firms were more likely to file provisional applications (as real options on future patent applications) under a first-to-file system. Furthermore, I show that the magnitude of this effect depended on contingencies such as the firm's technological dominance, industry concentration and patent effectiveness. These findings highlight the value of a real options lens for studying patent strategy.

Patent term has been a significant topic in the appropriability strategy literature and throughout the history of U.S. patent law. However, a dearth of empirical work centers on how various invention attributes impact firms' preferences for the length of patent term. In Chapter 4, I seek to addresses this gap in the literature by examining firms' revealed preference to file a patent immediately before (relative to after) the U.S. transition from the 17-years-from-issuance to 20-years-from-filing patent term, ushered in by TRIPS. I view this choice as firms' purchase of real options in patent term extension and show that patent prosecution uncertainty increases the value of these options, among other invention attributes. This study takes an exploratory approach and contributes to the literature on real options in innovation as well as appropriability strategy.

TABLE AND FIGURE

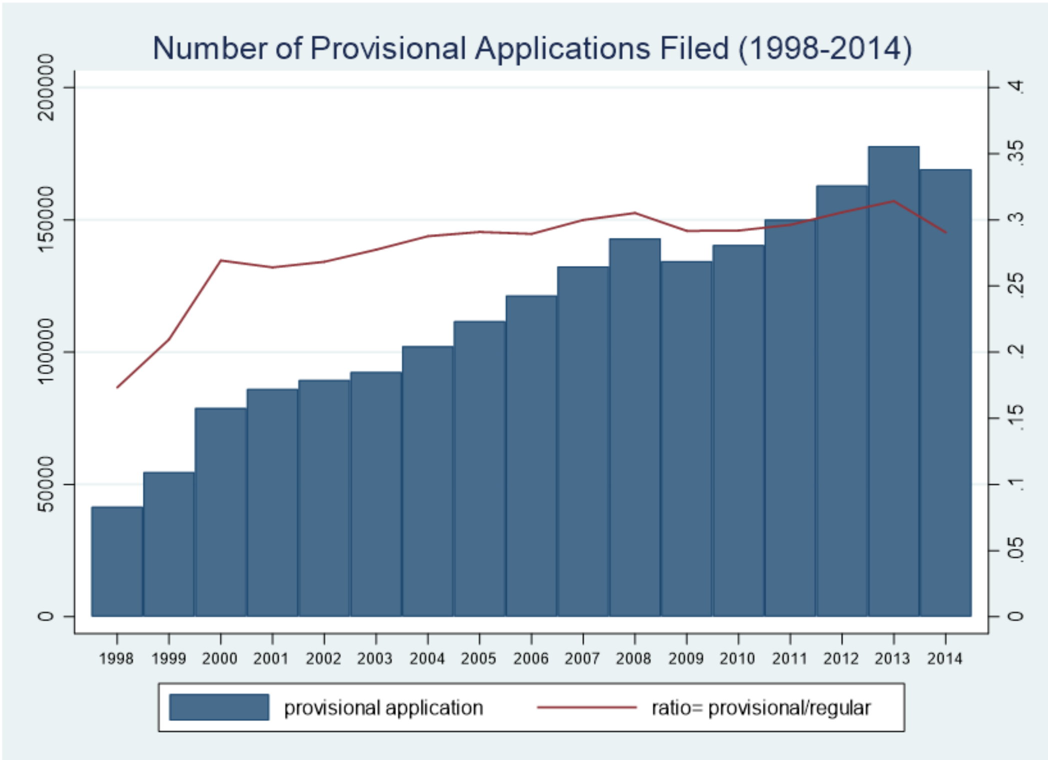
Table 1.1: Filing fees for regular versus provisional applications in my sample period ($ per application)

Year		1998	1999	2000	2001	2002	…	2010	2011	2012	2013	2014
Regular	Small	395	380	345	355	370	…	165	165	190	140	140
	Large	790	760	690	710	740	…	330	330	380	280	280
Provisional	Small	75	75	75	75	80	…	110	110	125	130	130
	Large	150	150	150	150	160	…	220	220	250	260	260
Dissertation sample period		Chapter 2						Chapter 3				

Source: The United States Patent and Trademark Office (USPTO) Federal Register Notices

N.B. An applicant qualified as a small entity pays lower filing fees. The USPTO defines small entity as either an individual inventor, a collaboration of individual inventors, a nonprofit organization, or a company with fewer than 500 employees.

Figure 1.1: The number of provisional patent applications filed during 1998-2014



Source: The United States Patent and Trademark Office (USPTO) Annual Reports

N.B. In computing the ratio, I exclude design applications from regular applications for comparison purposes since provisional applications cannot be subsequently filed as design applications (Migliorini, 2007).

CHAPTER 2: REAL OPTIONS IN VALUE APPROPRIATION: AN APPLICATION TO THE PATENT-SECRECY CHOICE

INTRODUCTION

How do firms profit from innovation is a fundamental research question in the technology strategy literature, which has long recognized the significant challenges posed by technological uncertainty for capturing value from innovation (e.g., Teece, 1986). Value appropriation strategies to capture profits from innovation are widely understood to be critical for firms (e.g., Lepak et al., 2007; Nordhaus, 1969; Teece, 1986; Scherer, 1965), while also being deployed under significant uncertainties regarding the technology and its commercial prospects. Real options reasoning (ROR), a theoretical lens that has informed how firms make strategic decisions under uncertainty (Hackbarth & Johnson, 2015; Li et al., 2007; Trigeorgis & Reuer, 2017), has also offered important insights into how value-creating R&D investments can be staged to balance strategic commitment and innovation-related uncertainties (e.g., Hurry et al., 1992; Mitchel & Hamilton, 1988; McGrath, 1997; McGrath & Nerkar, 2004). However, despite the large body of research on real options related to the creation of value through innovation, how ROR can inform firms' decision-making in value appropriation strategies has received relatively little scrutiny. In this paper, I highlight the value of a real options lens for appropriability strategies by examining the choice between patents and secrecy, and explaining when and why firms take advantage of real options to delay this choice in the patenting process (in essence retaining a "secrecy option" while obtaining a patent).

Research on real options in the IP literature suffers from the same lacunae affecting the strategic real options literature generally; namely, a lack of research on how firms choose among alternative IP rights as real options in their value appropriability strategies. For example, prior research has studied the exercise of IP-related real options to shed light on the value distribution of underlying inventions (Pakes, 1986), and examined the acquisition of IP rights as a real option on the future value that may be created from an invention (McGrath & Nerkar, 2004; Nerkar et al., 2007; Ziedonis, 2007). Examining firms' strategic choice of IP rights with a real options lens is valuable because there are substantial *ex ante* uncertainties – technological, commercial, and/or legal – that firms face when acquiring IP rights. ROR enables firms to avoid making costly commitments before these uncertainties are resolved, and thus preserves valuable future decision rights (e.g., Li et al., 2007; Trigeorgis & Reuer, 2017). At the same time, examining the patent-secrecy choice using a real options lens departs from the conventional static view of the choice between alternative IP rights (e.g., Horstmann et al., 1985; Levin et al., 1987), and instead sheds light on how firms may manage such decision making over time (e.g., Cohen et al., 2000; Graham, 2004) while awaiting the resolution of important uncertainties.

Thus, the core research question addressed in the current paper is: what drives firms to acquire real options that allow them to delay their choice between two mutually exclusive IP mechanisms, namely secrecy and patents. While patenting necessarily vitiates secrecy due to the enabling disclosure requirement enshrined in patent law[3] (Graham & Somaya, 2004) and fosters spillovers to rivals (Mansfield et al., 1981), significant *ex ante* uncertainties surrounding patenting (e.g., Lemley & Shapiro, 2005; Pakes, 1986; Somaya, 2012) may deter firms from committing to either mechanism before such uncertainties are resolved. Firms may seek to deal with this fundamental problem by purchasing real options that allow them to hedge between secrecy and patents. I refer to these options as "secrecy options" *conditional on pursuing patent protection*, and define them as choices whereby firms put a stake in the ground for patent

[3] A patent application must contain a written description of the technology, which enables any person skilled in the art to reproduce it (35 USC § 112(a)).

protection while preserving the right to withdraw from the patenting process without affecting their ability to retain secrecy of their technologies. Secrecy options are analogous to financial call options in that, at a relatively small cost, firms keep the upside potential of acquiring a patent right on an invention while at the same time limiting the downside risk of losing secrecy.

A firm's purchase of a secrecy option, the core phenomenon of interest in this study, is measured by the filing of a provisional patent application (hereinafter provisional), which allows the firm to lock in the priority date[4] for potential patent protection. A provisional then offers one year within which the patent applicant must file a regular (i.e., non-provisional) application with claims covering the same technology in order to continue with acquiring the patent right. Alternatively, a patent applicant may choose to back out of the patenting process and retain secrecy of its technology simply by doing nothing past the one-year milestone. Thus, a provisional enables a firm to gain a foothold in patent protection and simultaneously limits the downside risk of losing secrecy due to patenting – that is, to hedge its bets between patenting and secrecy (Lazar & Lohse, 2015).

In this study, I draw on real options theory to propose that the greater the risk of information disclosure to rivals due to patenting, the more likely that firms purchase secrecy options. Furthermore, I propose that in the presence of a heightened risk of information disclosure secrecy options are more valuable for (a) smaller firms, which often lack other value appropriation mechanisms to offset the loss of secrecy (e.g., Dushnitsky & Lenox, 2005; Katila et al., 2008), and for (b) more novel technologies, which have higher option value because they are associated with greater uncertainty (Ziedonis, 2007). I overcome potential empirical challenges in exogenously measuring information disclosure through patents by leveraging the

[4] Priority date is the earliest filing date, from which a patent applicant has a legal claim over the invention as the first inventor.

American Inventors Protection Act (AIPA), a quasi-exogenous change in U.S. patent law that went into effect on November 29, 2000 and caused substantially faster disclosure of technologies pursuing patent protection through a new 18-month publication rule. Moreover, this change primarily affected patent applicants that were seeking domestic U.S.-only protection, when compared with applicants that were also seeking patent protection in other countries that already had 18-month publication requirements of their own. I take advantage of these differences between patent applicants in a differences-in-differences empirical design, which allows stronger identification of my hypothesized effects. The empirical analyses provide support for all hypotheses at economically and statistically significant levels.

The main contributions of this study are three-fold. First, it informs the real options literature by shedding light on what drives firms to acquire real options in value appropriation choices, in contrast with the literature's prior focus on choices related to investments for value creation. Second, the study contributes to research on appropriability strategies by showing how firms may manage the choice between the alternative IP rights of patents and secrecy over time, departing from the conventional static view. Finally, the study makes empirical contributions by employing a novel dataset on provisional patent applications and designing a robust test leveraging a quasi-exogenous shock, in the analyses of firms' purchase of secrecy options, which may depend on the speed of technology disclosure through patenting.

THEORY AND HYPOTHESES

Speed of disclosure through patenting

Patenting requires firms to make the irreversible commitment of giving up secrecy. The "enabling disclosure"[5] requirement for patenting stipulates that a patentee must disclose the technology to the public in exchange for the patent right (e.g., Mazzoleni & Nelson, 1998). Despite the patent system's aim to promote the diffusion of technologies, firms seeking to appropriate value from their innovations may be faced with the critical risks of disclosure through patenting (e.g., Modigliani, 1999; Watase, 2002). Because patenting facilitates information disclosure, rivals may be able to invent around technologies earlier and at lower costs (Mansfield et al., 1981). Such imitation risks make commitments to patenting costly (e.g., Cohen et al., 2000; Sichelman & Graham, 2010).

Meanwhile, patenting involves significant *ex ante* uncertainties that will typically only be resolved over time (e.g., Lemley & Shapiro, 2005; Pakes, 1986; Somaya, 2012). Firms often file patents at early exploratory stages in their technology development, not assured of the long-term value of these patents (Pakes, 1986). For example, firms may be unsure of whether they are capable of making products with their patents and/or whether there will be markets for the products. Firms may be also unsure of whether their patents will survive the risks of being invalidated by rivals (Lemley & Shapiro, 2005; Shapiro, 2003). In addition to these technological, commercial, and legal uncertainties, there may be other uncertainties which span the patentability of the technology and/or the amount of time that takes for rivals to imitate the technology (e.g., Friedman et al., 1991; Mansfield et al., 1981). Taken altogether, *ex ante* uncertainties exist in the value of patents relative to the value of secrecy for the protection of the focal technology.

[5] A patent application must contain a written description of the technology, which enables any person skilled in the art to reproduce it (35 USC § 112(a)).

As a key driver of ROR, uncertainty critically informs the tension between commitment and flexibility in strategic choices (e.g., Ghemawat, 1991; Smit & Trigeorgis, 2004; Trigeorgis & Reuer, 2017). In the context of this study, because of *ex ante* uncertainties, a firm may seek to avoid making strong commitments to patenting before being assured of the value of patents relative to that of secrecy inasmuch as these two IP mechanisms are incompatible for the protection of the single technology (Graham & Somaya, 2004). Thus, the firm may choose to purchase a secrecy option while entering into the patenting process.

The extent to which technology disclosure to rivals through patenting negatively affects the focal firm may depend on the speed of such disclosure. *Ceteris paribus*, faster disclosure facilitated by patenting can lead to far more negative consequences by allowing rivals to imitate technologies more rapidly. Not only does faster disclosure make the irreversible commitment of giving up secrecy more costly for the focal firm, it also requires the commitment be made earlier before uncertainties are resolved. Therefore, I propose that faster disclosure of technologies by the patent system will make secrecy options more valuable for the protection of these technologies. With faster disclosure, firms may prefer to make weaker commitments to patenting by purchasing secrecy options rather than make full-blown commitments directly. Hence, my main hypothesis:

H1. The faster the information about a technology is disclosed as a result of patenting, the more likely that a firm purchases a secrecy option.

Secrecy options and small firms

Firm size impacts decision making in IP strategies since it relates to the availability of resources to the firm (e.g., Arundel, 2001; Sichelman & Graham, 2010). Arundel (2001) uses European Community Innovation Survey (CIS) and finds that small firms considered secrecy more important relative to patents than did large firms. Sichelman and Graham's (2010) analyses of the Berkeley Patent Survey show that commitments to patenting can be perceived more costly by small than large firms not only because of the high costs of acquiring and enforcing the patent right but also because of the risks of imitation by others, to which small firms are more vulnerable (e.g., Dushnitsky & Lenox, 2005; Katila et al., 2008). Thus, in the baseline, secrecy options will be more valuable for smaller firms which choose to enter into the patenting process.

Furthermore, faster disclosure of technologies by the patent system may affect smaller firms more negatively. Small firms may have difficulty competing on other value appropriation mechanisms that can offset the loss of secrecy. On the one hand, small firms lack complementary resources for commercializing technologies (e.g., Rothaermel & Deeds, 2004; Teece, 1986). Faster disclosure of the technology of a small firm will facilitate large firms inventing around the technology earlier and commercializing the non-infringing solutions more easily with their greater complementary resources. Even if firms exactly imitated (as opposed to inventing around) the technology due to faster disclosure, the small firm might not be capable of enforcing the patent right because of prohibitively high legal costs. On the other hand, small firms may also lack lead time advantages and thus can be outpaced by large firms easily. Large firms may plausibly patent around more rapidly the technology of the small firm based on faster disclosure, preempting technological spaces which would have been strategically important to the small firm.

Based on the preceding logic, I posit that secrecy options are more valuable for smaller firms when faster disclosure takes place. Prior research on ROR suggests that the option value depends on the amount of downside risk that can be curtailed by the use of the option (Dixit & Pindyck, 1994). With faster disclosure, full-blown commitments to patenting may lead to greater negative consequences to smaller firms. These risks can be effectively mitigated by purchasing secrecy options while entering into the patenting process. Thus, I propose the following contingency hypothesis:

H2. The faster the information about a technology is disclosed as a result of patenting, the more likely that a firm purchases a secrecy option when the firm is smaller in size.

Secrecy options in patenting and invention novelty

Further insights from real options theory indicate that greater uncertainty increases the option value since uncertainty determines the downside risk that can be reduced by avoiding making strong commitments (Dixit & Pindyck, 1994). A technology that is more novel to the world may be associated with greater uncertainty in the evaluation of the technology (Ziedonis, 2007) and therefore in the choice between patents and secrecy for the protection of the technology. Greater uncertainty may arise from any factors that affect a firm's decision calculus in patent-secrecy choices: the value of the technology, the costs of acquiring a patent, the length of time that it takes for rivals to imitate the technology, the patentability of the technology, etc. (Friedman et al., 1991). Thus, secrecy options as mechanisms to hedge bets between patents and secrecy will be more valuable for the protection of more novel technologies.

Moreover, faster disclosure of technologies through patenting may affect more novel technologies more negatively because of the associated greater uncertainty. Faster disclosure, or earlier vitiation of secrecy, implies that a firm must make commitments earlier to either patenting or secrecy. The earlier foreclosure of the choices may be more detrimental for the protection of more novel technologies since uncertainty is only partially resolved leading up to the due date although these technologies are associated with greater uncertainty to begin with. Thus, firms are susceptible to making erroneous choices between patents and secrecy. By contrast, for less novel technologies, which are associated with less uncertainty, firms may not gain as much by waiting before making commitments. Faster disclosure may not have as large an impact on these technologies.

Taken altogether, I posit that secrecy options are more valuable for more novel technologies when faster disclosure takes place. With faster disclosure, full-blown commitments to patenting may lead to greater negative consequences for the technology when it is more novel and thus associated with greater uncertainty. A firm will be more likely to purchase a secrecy option for that technology since the net benefit of awaiting the resolution of uncertainty plausibly relative to making costly commitments to patenting directly is greater than that for a less novel technology. Therefore, the following contingency hypothesis:

H3. The faster the information about a technology is disclosed as a result of patenting, the more likely that a firm purchases a secrecy option when the technology is newer to the world.

DATA AND METHODS

Dependent variable: choice to file a provisional patent application

The dependent variable of this study is a firm's choice to purchase a secrecy option for the focal technology when initially entering into the patenting process. This choice is measured by an indicator variable which denotes a firm's filing of a provisional as opposed to a regular application (= 1 if the patent was initially filed as a provisional; = 0 if as a regular application).

It is noteworthy that firms do not file a provisional all the time: a firm files a provisional only when it perceives the existence of *ex ante* uncertainties in the value of acquiring the patent right relative to that of retaining secrecy for the protection of the focal technology. In the absence of these uncertainties, a firm would either (a) make full-blown commitments to patenting directly (by filing a regular application and having the patent issue in a timely manner) or (b) retain secrecy of the technology (by staying outside the patent system). There are significant costs to acquiring the patent right through filing a provisional and then filing a regular application within one year, compared with filing a regular application directly. First, the overall monetary costs of patent prosecution until issuance increase since a provisional requires a separate filing fee from a regular application. Second, the opportunity costs may increase since the provisional route generally delays the time of patent issuance – after which the patentee is able to enforce his/her right against others – because the technology is not examined by the patent office until after a regular application is filed.

It is also equally noteworthy that neither does the firm file a regular application all the time. Although regular applications also allow firms to back out of the patenting process without harming secrecy of the technologies until the time of mandatory disclosure, these secrecy options provided by regular applications are accessible at much higher costs than those provided by provisionals. First, filing provisionals does not require drafting claims and/or conforming to other stylistic formalities (Migliorini, 2007), which saves legal costs significantly. In fact, patent attorneys drafting provisionals charge on average a third of what they would charge for drafting regular applications (Lazar & Lohse, 2015). Second, the filing fee of provisionals is lower than that of regular applications. Third, provisionals do not require any further actions for withdrawing from the patenting process (since going past one year suffices), whereas regular applications require the timely submission of official requests for abandonment[6] (USPTO, 2016). Therefore, if a firm was to hedge its bets between patents and secrecy under uncertainties, it might as well do so by filing a provisional instead of a regular application.

Empirical context

Historically, the U.S. patent system disclosed the information contained in a patent application at the time of patent issuance. Thus, when the patent happened to be disapproved, the applicant was able to protect his/her technology with the alternative IP mechanism of secrecy (Watase, 2002). Contrary to the U.S., other countries had an 18-month publication rule whereby the information contained in a patent application was disclosed to the public at 18 months from the priority date, regardless of whether the patent issues or not. This early disclosure system aimed at facilitating the diffusion of knowledge and preventing the duplication of R&D by other firms (Johnson & Popp, 2003).

The U.S. enacted the American Inventors Protection Act (AIPA) on November 29, 1999 to reconcile its patent system with those of other countries as negotiated with Japan under Global Agreement on Tariffs and Trade (GATT). The AIPA went into effect on November 29, 2000 and implemented the same 18-month publication rule in the U.S. Given that an average patent application takes 2 to 3 years to issue a patent (e.g., Allison & Lemley, 2000; Popp et al., 2004), the implementation of an 18-month publication rule resulted in substantially faster disclosure of

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[6] The USPTO suggests the request for abandonment be delivered to examiners more than four weeks prior to the projected date of disclosure.

technologies pursuing patent protection compared with the past legal framework in the U.S. Figure 2.1 illustrates this point graphically.

Furthermore, the fact that other countries had already been enforcing an 18-month publication rule prior to the U.S. transition provides identification strategies for obtaining the control group of inventions pursuing foreign as well as U.S. protection, and the treatment group of inventions pursuing only U.S. protection.

Method

In my analyses of what drives firms to purchase secrecy options when initially entering into the patenting process, I employ a difference-in-differences (DID) design leveraging the AIPA, a quasi-exogenous change in U.S. patent law. I examine whether a pre- and post-AIPA change in the likelihood of filing a provisional for the treatment group is significantly greater than that for the control group. A DID design controls for any effects that might have been caused by variables which are common to both the treatment and the control groups (Card & Kruger, 1993).

I employ linear probability models with robust standard errors. I use linear models instead of the non-linear models of probit and logit because the goal of this study is to investigate the causal effect of AIPA on the filing of a provisional relative to a regular application rather than forecast probabilities. Further, because the true conditional expectation function is unknown, linear probability models work better than arbitrarily chosen non-linear models (Angrist & Pischke, 2009).

Taken altogether, I estimate the following linear probability models on a DID design (Wooldridge, 2010):

$$y = \beta_0 + \beta_1 dB + \delta_0 d2 + \delta_1 dB * d2 + x'\theta + u,$$

where y is the choice to file a provisional, $d2$ a dummy variable that indicates a post-AIPA patent, dB a dummy variable that indicates the treatment group of patents pursuing only domestic protection, and x a vector of other explanatory variables. The coefficient of interest, is the DID estimator δ_1, which is estimated by $\widehat{\delta_1} = (\bar{y}_{B,2} - \bar{y}_{B,1}) - (\bar{y}_{A,2} - \bar{y}_{A,1})$.

Data

I employ U.S. patent data on utility patents which establish their own priority date, namely “original” as opposed to “continuing” patents (Lemley & Moore, 2004), since provisionals by law cannot be filed claiming priority to previously filed applications. I then keep track of whether the focal patent was initially filed as a provisional or a regular application.

I focus my analyses on those patents that were filed November 28, 1998 through November 28, 1999 (pre-AIPA subsample) *or* November 29, 2001 through November 29, 2002 (post-AIPA subsample). I exclude the patents filed one year before and after the AIPA effective date November 29, 2000 in order to account for potential bias arising from firms gradually adjusting to the new incentives created by the legislative change.

In this sample I keep only those patents that took no more than 4 years to issue (i.e., grant lag $\leq$ 4 years). This procedure was aimed at making the pre- and post-AIPA subsamples more comparable since they need to be matched with NBER data, which only covers patents granted through 2006: but for this procedure, a larger proportion of the post-AIPA patents would remain unmatched because they tend to have issued later than the pre-AIPA patents. I then exclude “untreated” patents, those post-AIPA patents that pursued only domestic protection and opted out of an 18-month publication rule (Graham & Hegde, 2015).

Lastly, I match this final sample of 249,759 patents to Compustat data on the algorithm provided by the NBER USPTO-Compustat correspondence file (Bessen, 2009).

Explanatory variables

Post-AIPA: a dummy indicating whether the patent was initially filed after the AIPA effective date November 29, 2000

Domestic protection: a dummy indicating whether the patent belongs to the treatment group of patents pursuing only domestic protection

The interaction of these two variables represents a dummy indicating a post-AIPA patent that pursues only domestic protection.

Size: measured in two ways, (a) the (logged) number of patents filed by a patentee during the sample period, based on prior research that has found a strong positive correlation between this measure and firm size (e.g., Scherer, 1965) and (b) (logged) total assets for the compustat subsample

Novelty: measured by the "originality" score based on backward citations (Trajtenberg et al., 1997), computed as $Originality_i = 1 - \sum_j^{n_i} s_{ij}^2$, where s_{ij} denotes the percentage of citations made by patent *i* that belong to patent class j, out of n_i patent classes. This Herfindahl concentration index based measure will be high [low] if the patent cites prior patents which belong to a wide [narrow] set of technologies.

I control for the following variables:

Technology categories: a set of 6 indicator variables denoting each of the 6 technology categories[7] the patent belongs to: chemical (12.8% of patents in the sample); computers and communications (22.4%); drugs and medical (8.6%); electrical and electronic (22.9%); mechanical (17.3%); others (16%)

Number of forward citations: the patent value measured by the number of forward citations (e.g., Abrams et al., 2013; Hall et al., 2005), adjusted for truncation bias with technology class-year fixed effects

Number of backward citations: the patent value measured by the number of backward citations (e.g., Harhoff et al., 2003)

Number of claims: the number of claims as a proxy for the complexity of the patent and the likelihood of legal disputes (Harhoff et al., 2003; Lanjouw & Schankerman, 2001)

To implement a DID design, I use interaction variables. The coefficient on the interaction of *Post-AIPA* and *Domestic protection* shows firms' purchase of secrecy options as a result of AIPA. I further interact this interaction variable with the measures of size and novelty respectively, creating three-way interactions. Requisite two-way interactions are also included wherever the three-way interactions are used.

RESULTS

The descriptive statistics illustrated in Figure 2.2 suggests that based on my sample, the mean rate of using a provisional varies by the patentee type and industry, and whether the patent pursues foreign protection. The most frequent users of provisionals were those classified as small

[7] This aggregate NBER classification scheme was developed by Hall et al. (2001) based on the more than 500 USPTO technology classes.

entities[8] by the USPTO (15.23%) – particularly U.S. individuals (15.5%) – and the drugs and medical industry (17.07%). In addition, provisionals were on average used more often for technologies pursuing only domestic protection (13.19%) than those pursuing foreign as well as domestic protection (8.08%).

Table 2.1 reports the summary statistics of explanatory variables by pre- and post-AIPA and the control and treatment groups.

As a preliminary step, I investigate whether a change in the probability of purchasing a secrecy option (i.e., filing a provisional as opposed to a regular application) for the treatment group was on average any different from that for the control group. Figure 2.3 shows that there was a much larger increase in the use of provisionals for the treatment than control group, after AIPA went into effect.

The descriptive statistics reported in Table 2.2 shows that the mean probability of filing a provisional increased post-AIPA for each of the four groups: (a) control-noncompustat; (b) control-compustat; (c) treatment-noncompustat; and (d) treatment-compustat. Most notably, the treatment-noncompustat group experienced an 89.6% mean probability increase in relative terms (from 0.125 to 0.237). The treatment-compustat group experienced a 33.3% increase (from 0.078 to 0.104), which is the second largest. These are larger increases than what was experienced by the control group (+21.1% in control-noncompustat and +18.2% in control-compustat). Moreover, relative percentage increases in the mean probability were greater for non-compustat than compustat applicants in both the treatment and the control groups. Thus, it appears that small firms on average valued provisionals more than large firms as AIPA went into effect.

[8] The USPTO defines small entity as either an individual inventor, a collaboration of individual inventors, a nonprofit organization, or a company with fewer than 500 employees.

Hypothesis testing for H1

Then, I turn to my main analyses using a DID design, reported in Table 2.3. The DID estimate in the full sample suggests that the probability of purchasing a secrecy option for the treatment sample increased significantly more than that for the control sample as AIPA went into effect ($\beta=0.049$, p-value<0.01). In numeric terms, firms were 6.5% (0.016+0.049=0.065) more likely to file a provisional for the treatment group technologies, whereas firms were 1.6% more likely to file a provisional for the control group technologies. The DID estimate is equivalent to a striking 45.8% increase in the filing of a provisional post-AIPA relative to the mean rate pre-AIPA (0.049/0.107=0.458). These findings strongly corroborate H1 that the faster the information about a technology is disclosed as a result of patenting, the more likely that a firm purchases a secrecy option.

The second column in Table 2.3 reports the impact of AIPA on firms' filing of provisionals for the compustat subsample. The DID estimate suggests that although compustat firms increased their purchase of secrecy options post-AIPA ($\beta=0.009$, p-value<0.05), the effect is smaller in both magnitude and significance than non-compustat firms as inferred from the effect in the full sample. This result hints at size effects hypothesized in H2, which will be examined shortly.

Robustness check for H1 (1)

Before I move onto the testing of H2 and H3, I conduct robustness checks for the testing of H1. I examine how the filing of a provisional changes over time by estimating Model (1) using a set of quarterly dummies instead of the single time period indicator.

Figure 2.4 shows that firms were much more likely to purchase a secrecy option post-AIPA for the treatment than the control group. There was a 46.7% increase in the filing of a provisional post-AIPA relative to the mean rate pre-AIPA (0.05/0.107=0.467). This number is comparable to what has been suggested by the DID coefficient of the full sample column in Table 2.3. This finding is strongly corroborative of H1.

Robustness check for H1 (2)

I perform coarsened exact matching (CEM) (Iacus, King, & Porro, 2012) to control for potential selection into the treatment and control groups. Firms' choice to pursue foreign or domestic protection for their inventions can be driven by underlying invention characteristics, which may also drive the choice to file provisionals for these inventions. CEM addresses these selection concerns by making the treatment and control groups more similar in terms of the empirical distributions of invention characteristics, and allows the more precise estimation of the causal effect.

I perform CEM on four variables: (a) the number of forward citations, (b) the number of claims, (c) the number of backward citations, and (d) invention novelty. Prior research recognizes that these invention characteristics are correlated with technological opportunities and/or the value of technologies. These variables are also presumably correlated with firms' choice to pursue foreign or domestic protection and further with their choice to file provisionals. Table 2.4 shows the results of CEM.

The results of DID analyses on this matched dataset, reported in Table 2.5, offer strong support for H1. Moreover, the magnitude of DID estimates increased relative to what we have seen earlier in Table 2.3.

Hypothesis testing for H2 and H3

I test for H2 and H3 by interpreting the coefficients on the respective three-way interactions, which are the DID estimates of interest. For the easier interpretation of these interactions, I chart out the predicted probabilities of the firms' purchasing a secrecy option with respect to size and novelty. These probabilities are computed using Model (4) with the full sample.

In Table 2.6, the DID estimates involving firm size were negative significant for the full sample in both Model (2) ($\beta=-0.014$, p-value<0.01) and Model (4) ($\beta=-0.013$, p-value<0.01), which suggests that AIPA increased the filing of a provisional more sharply for smaller firms. Moreover, the effect was greater in magnitude for the non-compustat than compustat subsample as can be inferred by comparing the compustat subsample (Model (2) $\beta=-0.010$, p-value<0.01; Model (4) $\beta=-0.008$, p-value<0.01) with the full sample.

Furthermore, in order to mitigate potential concerns for the size variable, measured by the (logged) number of patents filed by the patentee during the sample period, I supplement it with another proxy for size. For the compustat subsample, I further measure firm size by (logged) total assets. As reported in the third column under Model (2) and Model (4), even with this alternative measure, I find the same results in support of H2 (Model (2) $\beta=-0.007$, p-value<0.01; Model (4) $\beta=-0.006$, p-value<0.1).

Figure 2.5 shows that the negative impact of firm size on the predicted probability of filing a provisional was more pronounced for the treatment group post-AIPA, as suggested by its steeper slope than that of the pre-AIPA treatment group. At one standard deviation below the mean size, if the invention was in the treatment group, the probability of filing a provisional would be 0.1294 pre-AIPA and 0.2318 post-AIPA (=79% more likely post-AIPA). Meanwhile, if an invention was in the control group, the probability would be 0.0982 pre-AIPA and 0.1274 post-AIPA (=30% more likely post-AIPA). These findings support H2 that the faster the information about a technology is disclosed as a result of patenting, the more likely that a firm purchases a secrecy option when the firm is smaller in size.

Finally, I examine the three-way interaction involving novelty, reported in Table 2.6. The DID estimate was positive significant for the full sample in Model (3) (β=0.045, p-value<0.01), which suggests that AIPA increased the filing of a provisional more sharply for firms with more novel inventions, in support of H3. In Model (4), the full model which includes both size and novelty variables, the DID estimate is positive significant for the full sample (β=0.019, p-value<0.1) but insignificant for the compustat subsample. This insignificant coefficient once size is controlled for suggests that invention novelty is correlated with firm size in predicting firms' choice to file a provisional.

Figure 2.6 shows that the positive impact of novelty on the predicted probability of filing a provisional is more pronounced for the treatment group post-AIPA, as suggested by its steeper slope than that of the pre-AIPA treatment group. At one standard deviation above the mean novelty, if an invention was in the treatment group, the probability of filing a provisional would be 0.0982 pre-AIPA and 0.1614 post-AIPA (=64% more likely post-AIPA). In contrast, if an invention was in the control group, the probability would be 0.0800 pre-AIPA and 0.0961 post-AIPA (=20% more likely post-AIPA).

Supplementary industry subsample analyses

In these supplementary analyses, I compare the marginal effect of AIPA across industries. The DID analyses reported in Table 2.7 show that all industries except software, and drugs and medical significantly increased the filing of a provisional as AIPA went into effect.

Even though drugs and medical were the most frequent users of provisionals based on the average rate of use reported in Figure 2.2, they did not significantly increase the filing of provisionals in response to AIPA. This finding may be attributed to strong patent protection conferred to this industry (e.g., Anton et al., 2006), which lead to little uncertainty over the value of patents relative to that of secrecy; patents are generally perceived as a better IP mechanism. Due to little uncertainty, the purchase of a secrecy option did not change by drugs and medical firms despite the faster disclosure of technologies induced by AIPA.

Likewise, software firms did not increase the use of a provisional post-AIPA, which may be attributed to weak patent protection conferred to them (e.g., Miller, 2014). The resulting little uncertainty over the value of patents relative to that of secrecy may have led software firms to generally perceive secrecy as a better IP mechanism. Further, software patents are by nature more complex and thus more difficult to be discovered by rivals than patents in other industries (Mulligan & Lee, 2012). Therefore, the incentive to increase the purchase of a secrecy option in response to AIPA may have been lower than other industries.

Additional analyses

In Table A.1 of Appendix A, I further investigate how various invention attributes – the numbers of forward citations, claims, and backward citations – within the firm influence its choice to file a provisional application (relative to a regular application) by using linear probability models with assignee fixed effects. I find that these correlates of patent value (Harhoff et al., 2003; Lanjouw & Schankerman, 2004) do not impact the firm's use of a provisional application when there is faster disclosure of inventions due to patenting (i.e., after the implementation of AIPA).

DISCUSSION AND CONCLUSION

This study examines what drives firms to acquire (purchase) real options in their choices of two mutually exclusive IP mechanisms, or secrecy and patents, under uncertainties. I propose that the higher the risk of technology disclosure to rivals, the greater the value of "secrecy options" in the initial acquisition of the patent right. Empirically, I leverage the enactment of AIPA and firms' use of provisionals, and show that patent applicants exposed to faster disclosure of technologies were more likely to purchase secrecy options. Strikingly, the filing of a provisional increased by 45.8% after AIPA went into effect. Moreover, consistent with prior research on knowledge misappropriation (e.g., Dushnitsky & Lenox, 2005; Katila et al., 2008) and IP strategies (e.g., Arundel, 2001; Sichelman & Graham, 2010), I find that the value of secrecy options in response to faster disclosure was greater for smaller firms. I also find that the option value in response to faster disclosure was greater for more novel technologies, confirming the predictions of real options theory (e.g., Dixit & Pindyck, 1994; Smit & Trigeorgis, 2004).

This study seeks to address the gap in the existing literature on real options in the innovation landscape, which focuses on the implications of ROR for value creation (e.g., Hurry et al., 1992; Mitchel & Hamilton, 1987; McGrath, 1997; McGrath & Nerkar, 2004; Schwartz, 2004; Schwartz & Moon, 2000). I highlight that ROR informs the drivers of firm heterogeneity in the context of not only value creation but also value appropriation. Furthermore, this study is one that makes more accurate valuations of real options, as called for by recent research in strategic management (Trigeorgis & Reuer, 2017), since it analyzes firms' purchase of secrecy options at the granular, invention level.

I also contribute to the literature on IP and appropriability strategies by examining how firms may manage decision making on the acquisition of IP rights over time. This study examines firms' use of real options to manage uncertainties concerning tradeoffs arising from the two mutually exclusive value capture mechanisms of patent protection and secrecy, and thus answers recent calls for research on the strategic management of IP rights (e.g., Somaya, 2012). My findings have valuable implications for managers seeking to potentially patent technologies that differ in their attributes and vulnerability to spillovers to rivals. For example, firms may seek to purchase secrecy options more heavily for product innovations, which rivals can reverse engineer and invent around more easily than process innovations. Future research can study the over-time processes in which firms choose from different value appropriation mechanisms based on technology attributes correlated with spillovers to rivals.

This study also has important policy implications since it shows how patent applicants can hedge their bets between secrecy and patents for the protection of the same technology, which may potentially hinder the prompt dissemination of knowledge. Nevertheless, this study does *not* argue that firms on average prefer retaining secrecy of technologies to disclosing them through patenting. While innovating firms may be faced with conflicting incentives between hiding and disclosing technologies (e.g., Clarkson & Toh, 2010; Graham & Hegde, 2015), this paper shows that as technologies are disclosed faster on the margin, real options which enable firms to hedge bets between secrecy and patent protection become more valuable. Substantial *ex* *ante* uncertainties surrounding the value of patent protection relative to the value of secrecy in the early stage of innovation processes make the purchase of these options valuable.

Finally, I study what drives firms to *purchase* secrecy options (i.e., file provisionals) based on granted patents, and do not study the *exercise* of these options. We cannot observe what provisionals led to the eventual filing of a regular application or the eventual withdrawal from the patenting process because they are examined only after a regular application is subsequently filed. Although examining the determinants of the purchase of secrecy options is in and of itself interesting from both theoretical and practical standpoints, it would have been useful to know what happened to the exercise of these options.

TABLES AND FIGURES

TABLE 2.1: Summary statistics (N=249,759 patents)

	Pre-AIPA foreign (n=92,227 patents)				Post-AIPA foreign (n=91,622 patents)			
	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
No. of forward citations	1.08	1.727	0	59.98	0.887	1.506	0	49.48
Chemical	0.153	0.36	0	1	0.139	0.346	0	1
Computers & Communications	0.214	0.41	0	1	0.209	0.406	0	1
Drugs & Medical	0.106	0.308	0	1	0.079	0.27	0	1
Electrical & Electronic	0.212	0.409	0	1	0.252	0.434	0	1
Mechanical	0.171	0.377	0	1	0.184	0.388	0	1
Others	0.144	0.351	0	1	0.137	0.344	0	1
No. of claims	16.942	13.514	1	596	17.759	14.032	1	522
No. of backward citations	8.74	12.183	0	430	9.829	17.135	0	736
PostAIPA	0	0	0	0	1	0	1	1
Size: no. patents per assignee (L)	4.28	2.367	0.693	8.521	4.356	2.361	0.693	8.521
Size: total assets (L)	9.505	1.839	-0.719	12.647	9.728	1.623	-3.963	13.481
Novelty	0.527	0.339	0	1	0.535	0.337	0	1
	Pre-AIPA domestic (n=42,323 patents)				Post-AIPA domestic (n=23,587 patents)			
	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
No. of forward citations	1.12	1.594	0	36.107	0.924	1.521	0	43.034
Chemical	0.078	0.269	0	1	0.079	0.269	0	1
Computers & Communications	0.248	0.432	0	1	0.281	0.449	0	1
Drugs & Medical	0.071	0.257	0	1	0.059	0.236	0	1
Electrical & Electronic	0.212	0.409	0	1	0.236	0.424	0	1
Mechanical	0.16	0.367	0	1	0.163	0.369	0	1
Others	0.23	0.421	0	1	0.183	0.387	0	1
No. of claims	17.071	12.417	1	247	19.637	14.175	1	364
No. of backward citations	9.483	10.865	0	326	11.571	17.111	0	736
PostAIPA	0	0	0	0	1	0	1	1
Size: no. patents per assignee (L)	4.324	2.57	0.693	8.521	4.417	2.626	0.693	8.521

TABLE 2.1 (continued)

Size: total assets (L)	9.142	1.957	-0.719	12.625	9.658	1.759	-3.963	12.988
Novelty	0.517	0.335	0	1	0.541	0.326	0	1

TABLE 2.2: Mean use of a provisional (N=249,759 patents)

		Non-compustat		Compustat	
		Pre-AIPA	Post-AIPA	Pre-AIPA	Post-AIPA
Foreign protection (CON)	Mean	0.071	0.086	0.077	0.091
	Std. err.	(0.001)	(0.001)	(0.001)	(0.002)
	No. obs.	60,416	58,327	31,811	33,295
Domestic protection (TRT)		0.125	0.237	0.078	0.104
		(0.002)	(0.004)	(0.002)	(0.003)
		26,539	12,780	15,784	10,807

TABLE 2.3: Linear probability model for use of a provisional

	Model (1)	
	Full sample	Compustat subsample
No. of forward citations	0.006***	0.003***
	(0.000)	(0.001)
Chemical	0.022***	0.035***
	(0.002)	(0.004)
Computers & Communications	-0.022***	-0.026***
	(0.002)	(0.003)
Drugs & Medical	0.078***	0.127***
	(0.003)	(0.006)
Electrical & Electronic	-0.012***	-0.015***
	(0.002)	(0.003)
Others	0.017***	0.026***
	(0.002)	(0.005)
No. of claims	0.002***	0.001***
	(0.000)	(0.000)
No. of backward citations	0.002***	0.001***
	(0.000)	(0.000)
Domestic protection	0.035***	0.008***
	(0.002)	(0.003)
PostAIPA	0.016***	0.015***
	(0.001)	(0.002)
PostAIPA * Domestic protection	0.049***	0.009**
	(0.003)	(0.004)
Constant	0.019***	0.039***
	(0.002)	(0.003)
No. obs.	245,283	90,466

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Technology category dummies included, with mechanical as the reference category.

TABLE 2.4: Coarsened exact matching (CEM) results

Panel A: Matching results

	Foreign protection (CON)	Domestic protection (TRT)
All	183,849	65,910
Matched	65,721	65,721
Unmatched	118,128	189

Panel B: Means for treatment and control groups before and after matching

	No. forward citations	No. claims	No. backward citations	Novelty
CON before matching	1.029	17.650	10.000	0.531
TRT before matching	1.078	18.160	10.760	0.525
Difference	-0.049***	-0.508***	-0.754***	0.006***
Mean test t-statistic	-6.290	-7.824	-10.770	3.572
CON after matching	1.008	17.510	9.754	0.526
TRT after matching	1.055	18.070	10.530	0.525
Difference	-0.047***	-0.562***	-0.780***	0.000
Mean test t-statistic	-5.701	-7.689	-11.830	0.255

TABLE 2.5: Coarsened exact matching (CEM) and linear probability model for use of a provisional

	Full sample	Compustat subsample
Chemical	0.022***	0.028***
	(0.003)	(0.005)
Computers & Communications	-0.031***	-0.032***
	(0.003)	(0.004)
Drugs & Medical	0.075***	0.122***
	(0.004)	(0.007)
Electrical & Electronic	-0.018***	-0.018***
	(0.003)	(0.004)
Others	0.015***	0.019***
	(0.003)	(0.006)
Domestic protection	0.034***	0.009***
	(0.002)	(0.003)
PostAIPA	0.017***	0.014***
	(0.002)	(0.004)
PostAIPA * Domestic protection	0.054***	0.013**
	(0.003)	(0.005)
Constant	0.074***	0.080***
	(0.003)	(0.004)
Observations	131,315	50,103

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Technology category dummies included, with mechanical as the reference category.

TABLE 2.6: Linear probability model for use of a provisional

	Model (2)			Model (3)		Model (4)		
	Full sample Size: no. patents per assignee (L)	Compustat Size: no. patents per assignee (L)	Compustat Size: total assets (L)	Full sample	Compustat	Full sample Size: no. patents per assignee (L)	Compustat Size: no. patents per assignee (L)	Compustat Size: total assets (L)
No. of forward citations	0.006***	0.003***	0.002***	0.006***	0.003***	0.006***	0.003***	0.002***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Chemical	0.028***	0.032***	0.031***	0.021***	0.033***	0.028***	0.030***	0.028***
	(0.002)	(0.004)	(0.004)	(0.002)	(0.004)	(0.002)	(0.004)	(0.004)
Computers & Communications	0.007***	-0.004	-0.020***	-0.022***	-0.025***	0.007***	-0.004	-0.020***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)
Drugs & Medical	0.079***	0.104***	0.104***	0.077***	0.123***	0.076***	0.098***	0.098***
	(0.003)	(0.006)	(0.006)	(0.003)	(0.007)	(0.004)	(0.007)	(0.007)
Electrical & Electronic	0.009***	0.001	-0.015***	-0.012***	-0.014***	0.010***	0.001	-0.014***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)
Others	0.004*	0.011**	0.014***	0.018***	0.028***	0.004	0.012***	0.015***
	(0.002)	(0.005)	(0.005)	(0.002)	(0.005)	(0.002)	(0.005)	(0.005)
No. of claims	0.002***	0.001***	0.001***	0.002***	0.001***	0.002***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
No. of backward citations	0.001***	0.001***	0.001***	0.002***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Domestic protection	0.040***	-0.024**	-0.079***	0.041***	0.017***	0.045***	-0.013	-0.068***
	(0.004)	(0.009)	(0.015)	(0.003)	(0.004)	(0.005)	(0.011)	(0.016)
PostAIPA	0.038***	0.083***	0.167***	0.015***	0.018***	0.039***	0.091***	0.172***
	(0.003)	(0.009)	(0.017)	(0.002)	(0.004)	(0.004)	(0.010)	(0.018)
Size	-0.010***	-0.018***	-0.017***			-0.010***	-0.018***	-0.017***
	(0.000)	(0.001)	(0.001)			(0.000)	(0.001)	(0.001)
PostAIPA * Domestic protection	0.103***	0.075***	0.080***	0.026***	-0.004	0.089***	0.058***	0.055*
	(0.008)	(0.017)	(0.029)	(0.006)	(0.007)	(0.010)	(0.019)	(0.031)
Domestic protection * Size	-0.003***	0.005***	0.009***			-0.003***	0.005***	0.008***
	(0.001)	(0.001)	(0.002)			(0.001)	(0.001)	(0.002)
PostAIPA * Size	-0.005***	-0.012***	-0.015***			-0.005***	-0.012***	-0.016***
	(0.001)	(0.001)	(0.002)			(0.001)	(0.001)	(0.002)
Domestic protection * PostAIPA * Size	-0.014***	-0.010***	-0.007***			-0.013***	-0.008***	-0.006*
	(0.001)	(0.002)	(0.003)			(0.001)	(0.003)	(0.003)
Novelty				0.024***	0.022***	0.019***	0.017***	0.020***
				(0.002)	(0.004)	(0.002)	(0.004)	(0.004)
Domestic protection * Novelty				-0.016***	-0.020***	-0.015***	-0.019**	-0.017**
				(0.005)	(0.008)	(0.006)	(0.008)	(0.008)
PostAIPA * Novelty				0.002	-0.005	0.000	-0.008	-0.003
				(0.004)	(0.006)	(0.004)	(0.006)	(0.006)
Domestic protection * PostAIPA * Novelty				0.045***	0.023*	0.019*	0.012	0.013
				(0.009)	(0.012)	(0.010)	(0.012)	(0.012)
Constant	0.051***	0.140***	0.209***	0.008***	0.029***	0.044***	0.133***	0.201***
	(0.002)	(0.006)	(0.011)	(0.002)	(0.004)	(0.003)	(0.007)	(0.012)
No. obs.	216,500	90,466	90,449	227,552	84,866	200,680	84,866	84,849

Robust standard errors in parentheses*** p<0.01, ** p<0.05, * p<0.1; Technology category dummies included, with mechanical as the reference category.

TABLE 2.7: Linear probability model for use of a provisional (industry subsample analyses)

	Chemical	Computers& Communications -software	Computers& Communications -other	Drugs& Medical	Electrical& Electronic	Mechanical	Others
No. of forward citations	0.006***	0.009***	0.013***	0.001	0.008***	0.007***	0.003**
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
No. of claims	0.002***	0.001***	0.001***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
No. of backward citations	0.002***	0.001***	0.002***	0.001***	0.002***	0.001***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Domestic protection	0.034***	-0.020***	0.038***	0.021**	0.037***	0.061***	0.052***
	(0.006)	(0.005)	(0.004)	(0.008)	(0.003)	(0.004)	(0.004)
PostAIPA	0.007**	0.034***	0.024***	-0.018***	0.017***	0.019***	0.024***
	(0.004)	(0.005)	(0.003)	(0.006)	(0.002)	(0.003)	(0.003)
PostAIPA * Domestic protection	0.056***	-0.001	0.031***	-0.008	0.052***	0.070***	0.073***
	(0.012)	(0.008)	(0.008)	(0.014)	(0.006)	(0.008)	(0.008)
Constant	0.042***	0.021***	0.000	0.137***	-0.005**	0.000	0.017***
	(0.003)	(0.005)	(0.003)	(0.005)	(0.002)	(0.003)	(0.003)
No. obs.	30,841	17,057	38,474	19,956	56,709	42,805	39,441

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

FIGURE 2.1: Pre-AIPA versus post-AIPA legal framework

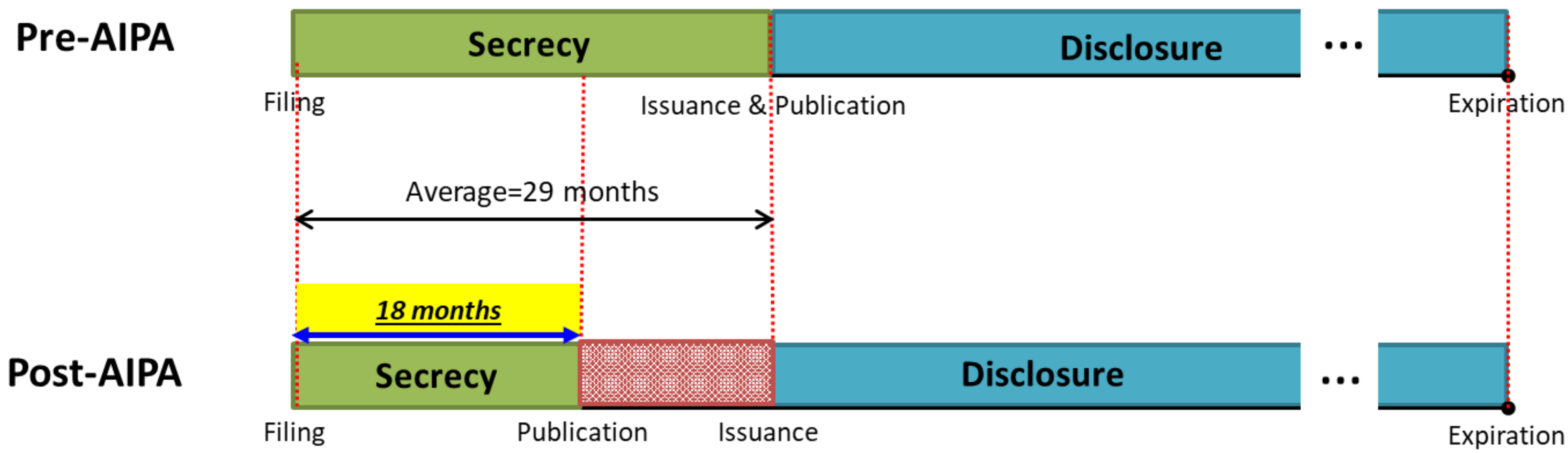


FIGURE 2.2: Mean use of a provisional

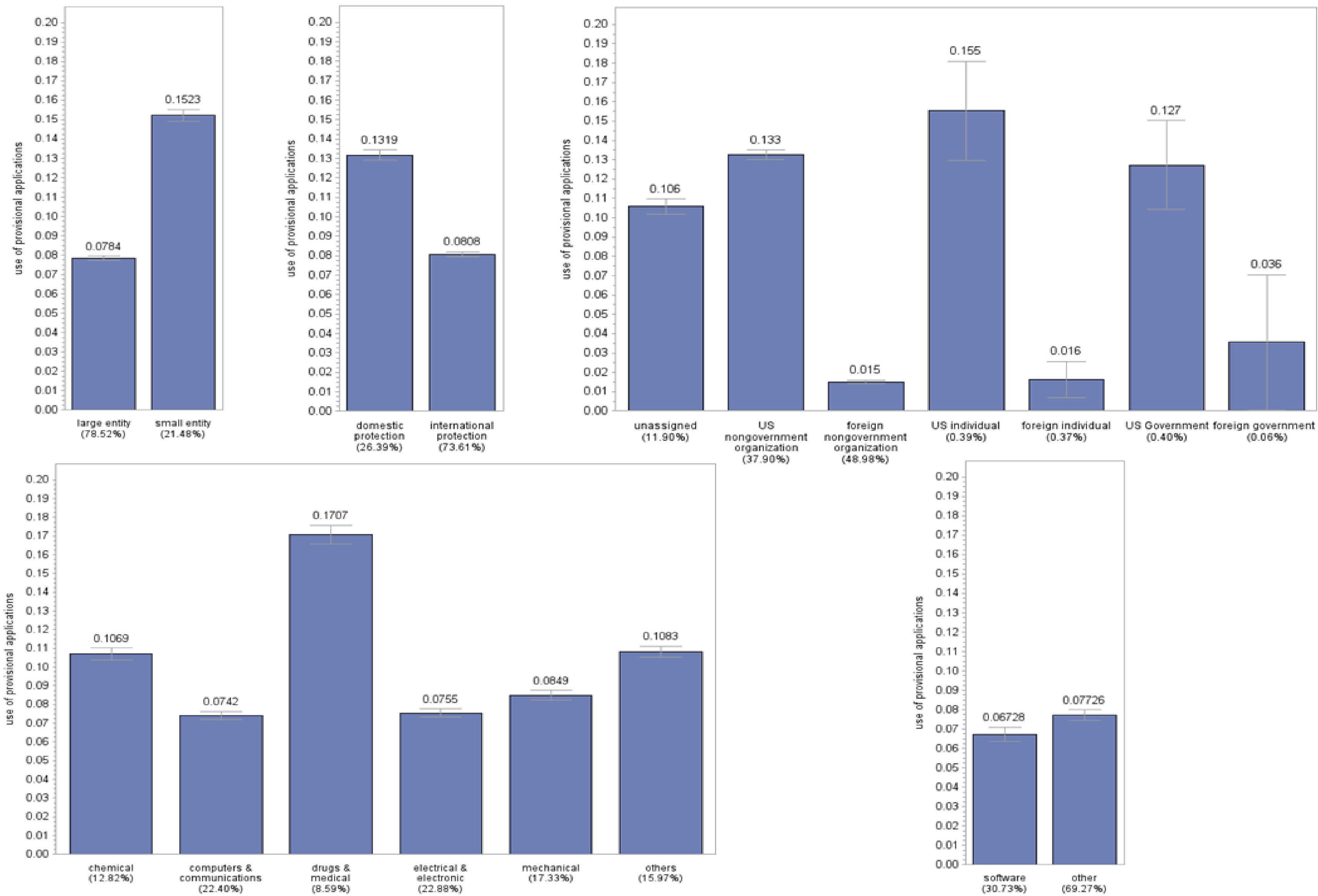


FIGURE 2.3: Mean use of a provisional per month

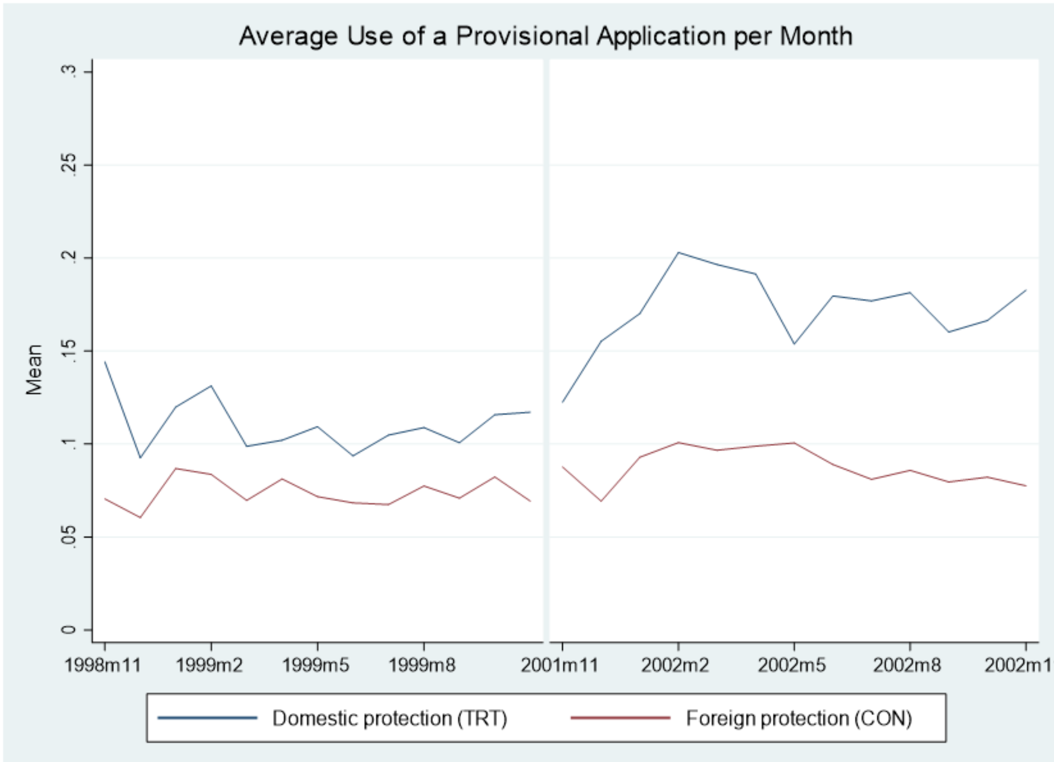
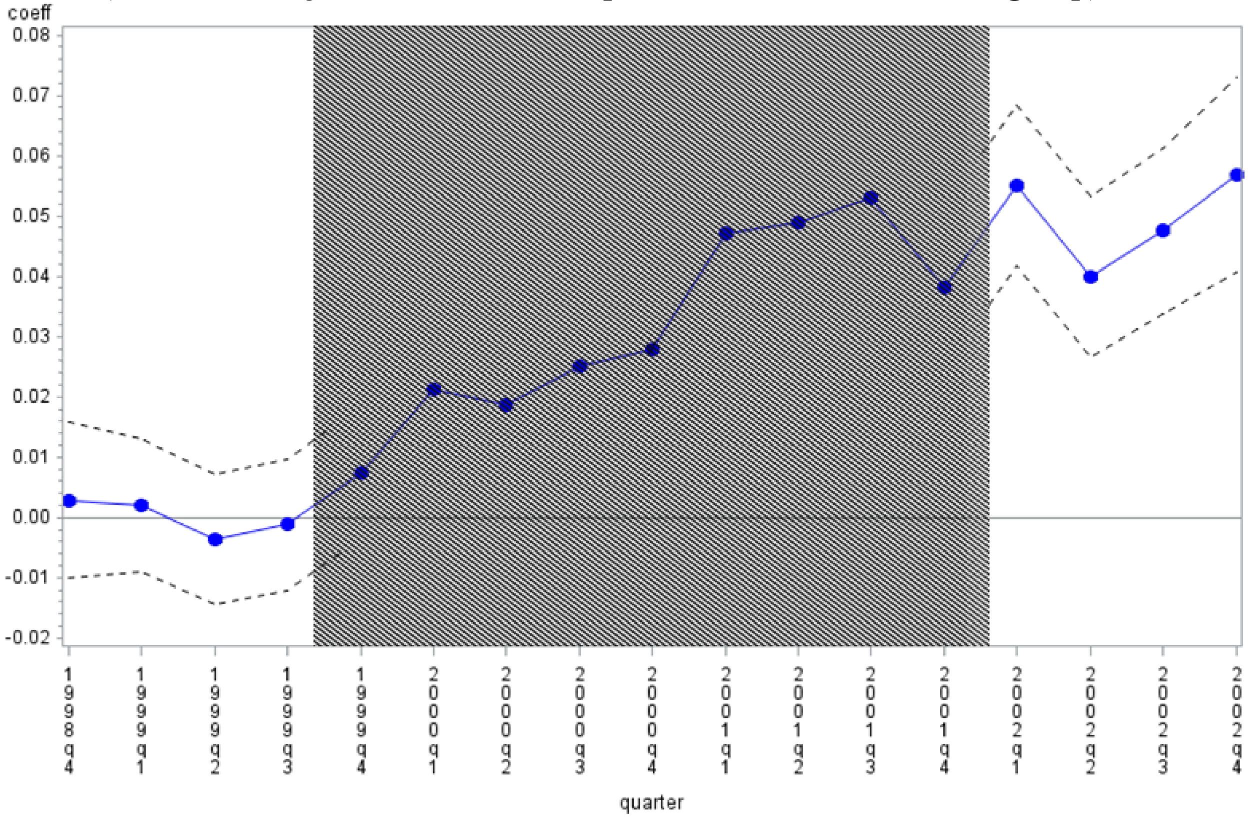


FIGURE 2.4: Quarter window to/from AIPA effective date
(coefficients adjusted in reference to pre-AIPA mean in treatment group)



2000q4, the quarter of the AIPA effective date, is the reference category t_0.

FIGURE 2.5: Interaction effects on use of a provisional for firm size

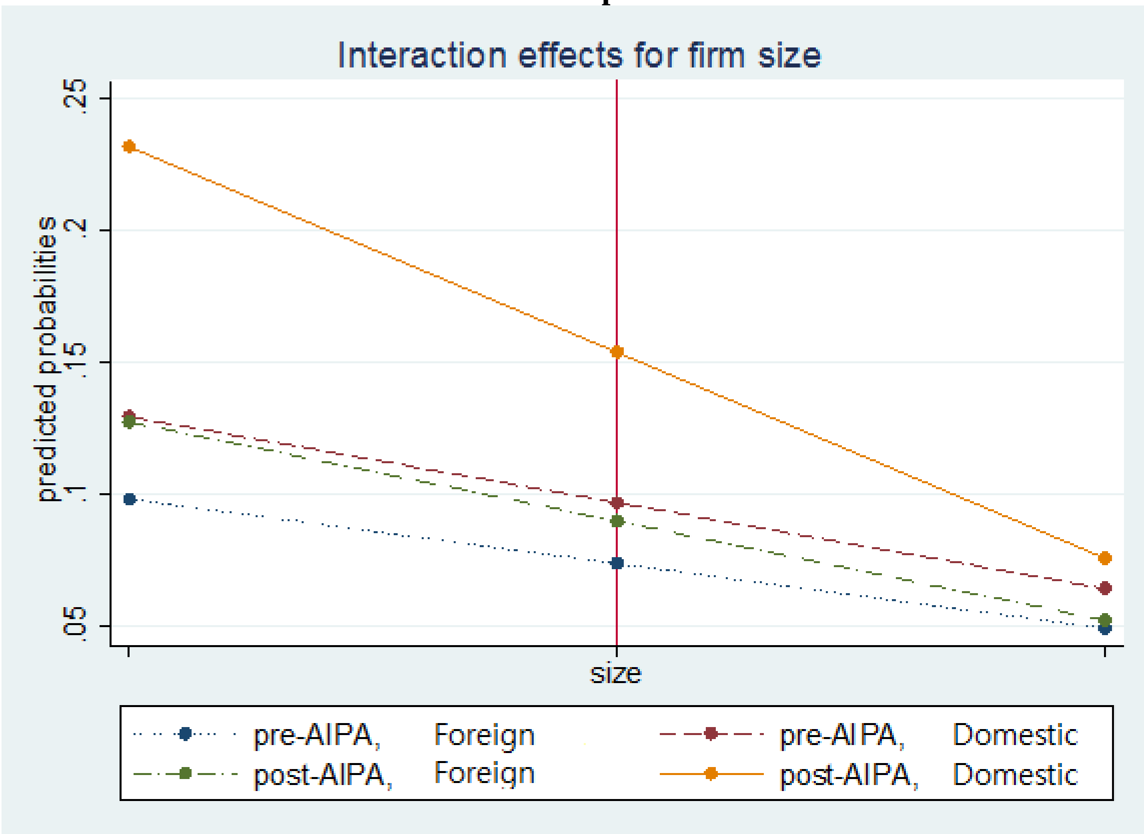
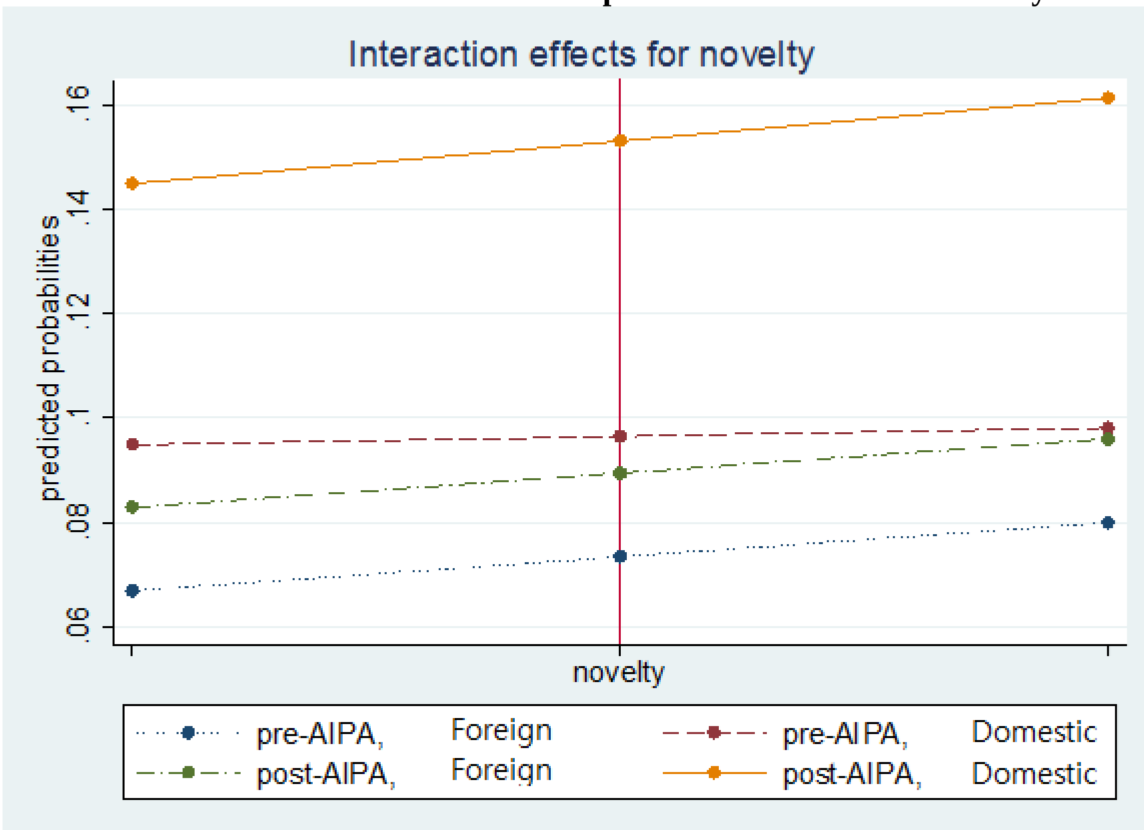


FIGURE 2.6: Interaction effects on use of a provisional for invention novelty



CHAPTER 3: RACING TO PATENT IN FIRST-TO-FILE PATENTING SYSTEMS: EVIDENCE FROM PROVISIONAL PATENT APPLICATIONS AND THE AMERICA INVENTS ACT (AIA)

INTRODUCTION

The patent system incentivizes firms to engage in inventive activity by rewarding them with an exclusive right to prevent others from making, using, or selling an invention (Mazzoleni & Nelson, 1998). However, the patent right to an invention is awarded on the first-past-the-post principle, whereby only the first firm to develop a new invention receives an exclusive property right. A firm that is second or third receives virtually no benefit for its efforts, which may result in energetic winner-take-all competition among firms to be the first in innovative races (Reinganum, 1989; Tirole, 1989). A stark example of such innovative races occurs in first-to-file (FTF) patent systems, in which the patent right goes to the first firm to file a patent application. FTF patent systems differ from first-to-invent (FTI) systems, which award patents to the first firm to invent a technology. In FTF systems, firms presumably have an incentive to race to the patent office by filing more patent applications, earlier in the development cycle (Case, 2013).

However, racing to patent is costly in terms of time as well as resources. In order to file a patent earlier, firms will need to accelerate R&D as well as the legal work of drafting an application. Due to time compression diseconomies (Dierickx & Cool, 1989), the acceleration of R&D and legal activities is likely to require more total resources than comparable innovation without the need for such acceleration. Additionally, when speeding up the process of invention and filing patents, firms may be more prone to making errors, which can undermine the value of any patents they are able to obtain. Thus, there are important strategic tradeoffs to consider in firms' innovation racing behavior, which suggest that firms might not always race to file patents in a FTF system. More generally, despite a stream of economics research on patent races (e.g., Cockburn & Henderson, 1994; Fudenberg et al., 1983; Isaac & Reynolds, 1988; Reinganum, 1989), strategic implications of the winner-take-all features of patent systems – such as the first-to-file rule – are in need of further theoretical development and empirical investigation.

In this paper, I propose that firms may capitalize on real options in the patenting process as a solution to the incentives and challenges they face in a FTF patenting system. In the U.S. patent system, such real options are provided by provisional patent applications, whereby firms can establish a patent claim on their invention without incurring the full costs of developing the invention or completing a detailed patent application. By filing a provisional application, firms secure the priority date for an invention and receive one year within which they can pursue patent prosecution by filing a regular patent application. A provisional application secures patent priority at substantially lower costs than a regular patent application and provides a firm with the right but not the obligation to file a regular application. Therefore, it can be understood as a real option on a patent application. More generally, the provisional application is an exemplar of a variety of real options available to patentees within the patent system, such as the right to withdraw applications (and preserve secrecy), the right to renew patents, the right to enforce them, and so on. Prior research suggests that such real options are especially important and valuable in patent strategy, which entails a sequence of decisions that are often surrounded by significant technological, commercial and legal uncertainties (Pakes, 1986; Somaya, 2012).

Building on this real options lens, I hypothesize that firms are more likely to "race to patent" under a FTF patent system (relative to a FTI system) by filing provisional applications. Drawing on prior theory regarding R&D and patent races, I further propose that the magnitude of this effect will depend on contingencies such as a firm's technological dominance, industry concentration, and industry patent effectiveness. Methodologically, I employ a difference-in-differences (DID) design that leverages the transition of the U.S. patent system from FTI to FTF following the America Invents Act (AIA). My findings shed light on an important and understudied research question – how do firms strategically respond to the first-past-the-post nature of patenting systems? These findings also highlight the importance and use of real options in patent strategy, using provisional patent applications as a specific example. Finally, I also contribute empirically to our understanding of patent races by employing data from a natural quasi-experiment that enables robust identification of causal relationships.

THEORY AND HYPOTHESES

Existing literature in industrial organization and appropriability strategy has studied why firms race to patent, quite independently of each other. I first highlight some of the motives for patent racing, combining these lines of research. I then examine how provisional patent applications can be viewed as real options on patents and what drives firms to purchase these real options in their race to patent.

Motives for patent racing

The patent right to an invention is awarded on the first-past-the-post principle, whereby only the first firm to develop a new invention receives the right to exclusive appropriability (i.e., the right to exclude others from making, using, and/or selling the same invention). It is these winner-take-all features of patent systems that fundamentally motivate firms to race to patent (Cockburn & Henderson, 1994; Lerner, 1997; Tirole, 1989).

Furthermore, prior research recognizes two “strategic” motives for patent racing (e.g., Blind et al., 2006; Cohen et al., 2000) – preemptive and defensive. First, the preemptive motive suggests that firms will race to patent inventions in hopes of preventing others from using the same and/or adjoining inventions (e.g., Gilbert & Newbery, 1982, 1984; Reinganum, 1983, 1984). Much of the empirical evidence suggests that the preemptive motive is considered important (e.g., Blind et al., 2006; Cohen et al., 2000; Pitkethly, 2001). More recently, Ceccagnoli (2009) finds that preemptive patenting positively affects firm performance. In the technology race framework in industrial organization, both technology leaders and laggards have incentives to race to patent for preemption. Given that patent applications are examined for issuance in light of prior art, preemptive patenting by one firm adds to prior art and makes it difficult for others to obtain any patents (Baker & Mezzeti, 2005; Lichtman et al., 2000). By preemptive patenting, the leader can raise the costs of competing for the laggard and drive him out of the technology race. By preemptive patenting, the laggard can buy time in the technology race and potentially catch up the leader.

On the other hand, the defensive motive is observed when firms race to patent inventions in order to prevent others from vitiating their freedom-to-operate (e.g., Hall & Ziedonis, 2001; Kingston, 2001). A fairly large body of research has explored conditions under which the defensive motive is more pronounced, most notably “multi-invention” contexts in which building a patent portfolio provides the owner bargaining power against numerous external patent holders in commercializing a product (e.g., Hall & Ziedonis, 2001; Somaya et al., 2011; Ziedonis, 2004). The firm can negotiate for better deals with external patent holders by owning a number of patents which these other firms may need for commercialization of their own products. Moreover, firms may pursue patents for inventions (even ones of little value) with the aim of creating prior art – so-called "defensive publishing" (e.g., Henkel & Jell, 2009; Henkel & Pangerl, 2008; Johnson, 2014) – since it will foreclose the possibility of others obtaining patents for the same inventions and threatening freedom-to-operate.

Provisional patent applications as real options

Under a FTF patenting system, the payoff attached to prompt filing of patents is higher because firms that file late may be preempted by an earlier patent filing irrespective of who was the first and true inventor. Thus, a FTF system reinforces the first-past-the-post, winner-take-all characteristic of the patent system and necessitates racing to obtain the patent right (Case, 2013).

However, racing to patent is costly and potentially risky. First, firms will need to accelerate R&D in order to file a patent sooner. With time compression diseconomies (Dierickx & Cool, 1989), firms will not be able to achieve the same productivity level of their R&D resources when accelerating innovation. Quite simply, innovating faster will require more total resources for the same innovative output. Moreover, when firms seek to accelerate innovation, they are more likely to commit errors, such as identifying the wrong technological solution or the wrong target market. Similarly, it might also be costly to speed up the legal work of preparing a patent application. An average patent application takes one to two weeks to prepare and demands the time and attention of the inventor even if a patent attorney drafts it (Case, 2013; Sichelman & Graham, 2010). The potential for errors are significant here as well, such as missing important prior art, not including an important patent claim, and so on. Indeed, it has been estimated that racing to patent can cost firms more than $1billion per year (Boundy & Marquardt, 2010).

Accordingly, I posit that obtaining real options on patent applications through provisional applications will be more valuable under a FTF (than FTI) system. Provisional applications allow firms to get their foot in the door of patent protection more quickly and at lower costs than regular patent applications. Requiring only a disclosure and no prior art references or patent claims, they allow firms to establish the patent priority date for an invention earlier in the development cycle. Applicants may then amend the application, add references and claims, and file a regular application within a year. Thus, provisional applications can be used to respond to the patent racing challenges posed by a FTF patent system while simultaneously avoiding many of the costs and risks associated with early patenting.

H1. Firms are more likely to use patenting real options (provisional patent applications) in a first-to-file (versus a first-to-invent) system.

Market structure

Prior research suggests that the market structure of an industry affects firms' incentives to race to patent (e.g., Gilbert & Newbery, 1982, 1984; Reinganum, 1983, 1984). However, there has been a long-standing debate on whether greater market power leads to higher or lower incentives to race to patent. One stream of research suggests that firms in more concentrated markets are more incentivized to race to patent because they are able to price the innovation higher from a neoclassical economics standpoint. Dasgupta and Stiglitz (1980) suggest that a firm with market power can sustain its position by "engaging in sufficiently fast research that it does not pay any other entrant to engage in any R&D" (p. 26). Following this logic, the benefits of patent racing under a FTF system may be greater when the industry is more concentrated, not only because the incumbent firms can anticipate higher ex-post profits but also because they face greater negative consequences of not racing to patent. For example, the patenting of a substitute invention by a potential entrant may significantly erode profits from existing inventions as well

(Gilbert & Newbery, 1982), and will be particularly detrimental for an incumbent with well-differentiated inventions that enjoy a higher markup.

Conversely, another stream of research suggests that the increased benefits of patent racing may be greater when the industry is less concentrated. Reinganum (1983) contends that a dominant incumbent has lower incentives to race to patent for fear that developing a new invention may result in the displacement of its existing invention. Thus, a less dominant firm like a potential entrant has a greater incentive to race to patent, which is also suggested by prior empirical evidence (Lerner, 1997). Following this logic, I expect to observe more aggressive patent racing in a less concentrated industry, wherein firms face greater incentives to race to patent in order to strengthen their market power in the future. Therefore, under a FTF system, firms in less concentrated industries may place a higher value on real options in patent application. Reflecting these alternative views on how market structure affects patent racing, I advance the following alternative hypotheses:

H2a. Firms are more likely to use patenting real options (provisional patent applications) in a first-to-file (FTF) system when their industry is more concentrated.

H2b. Firms are more likely to use patenting real options (provisional patent applications) in a first-to-file (FTF) system when their industry is less concentrated.

Technological dominance

Not all firms may be equally motivated to win a patent race and preempt rivals. Prior research suggests that a technologically dominant firm may be less concerned about being preempted in patent priority (Gandal & Scotchmer, 1993), due to the significant costs of racing to patent and because its dominant patent position may already deter other innovators to some degree. Moreover, technologically dominant firms can also profit from sequential innovations that are developed by others, but build on (and are also covered by) their own upstream patents (Scotchmer, 1991). Therefore, these dominant firms may even choose to collaborate with others (e.g., via research joint ventures or licensing agreements) to develop second-generation technologies and products that build on their patented inventions, rather than simply seeking to preempt such downstream innovation and patenting (Scotchmer, 1991).

Furthermore, a technologically dominant firm has a better understanding of inventions in the technology space than others. A firm understands new inventions based on existing inventions, whereby it accumulates knowledge in technology (Kaplan & Tripsas, 2008). A technologically dominant firm can thus have a superior repository of knowledge which is applicable to different technology situations. In decision-making in IP, a technologically dominant firm may know better the value of patents for its new inventions (i.e., less uncertainty in the value of patents) and thus may be less likely to use real options on patents, based on real options theory (Dixit & Pindyck, 1994).

Taken together, I posit that when a firm is technologically dominant (i.e., when others build more on the focal firm's inventions), the benefits of securing patent priority are lower relative to the costs of obtaining a real option on such a patent through a provisional application. A technologically dominant firm is unable to develop many derivative applications of its inventions efficiently by itself, so delegating some R&D to others can be efficient. Moreover, it perceives less uncertainty in the value of patents, due to its greater knowledge and experience in the technology space. Hence, a technologically more dominant firm will place a lower value on real options in patent applications than a technologically less dominant firm. Thus, *H3. Firms are more likely to use patenting real options (provisional patent applications) in a first-to-file (FTF) system when they have lower technological dominance.*

Patent effectiveness

Patent protection is considered ineffective when patents have high probabilities of being invalidated or being invented around (Anton et al., 2006). Because patenting is costly, firms are less likely to pursue a patent unless they can justify the significant costs of obtaining and enforcing a patent (Sichelman & Graham, 2010). These costs include the significant legal costs of conducting an extensive patent search (ranging $5000-$10,000 per application) and drafting patent applications (ranging $8,000-$15,000 per application) as well as straight-up filing, issuance, and maintenance fees to be paid to the patent office. The post-issuance legal costs of monitoring for potential infringement and defending against patent validity challenges are also nontrivial, even though the probability of the firm having to bring a lawsuit is low in general. Thus, when patents are ineffective, firms have less incentive to pursue them and may instead employ other appropriability mechanisms such as secrecy, complementary assets, and lead-time advantages (Cohen et al., 2000).

I submit that when patent protection is less effective, the value of a real option on a patent decreases because the value of the underlying asset (the patent) decreases. On the other hand, when patents are effective, firms will be more likely to race to patent by buying real options on patents. Therefore,

H4. Firms are more likely to use patenting real options (provisional patent applications) in a first-to-file (FTF) system when their industry is characterized by more effective patent protection.

DATA AND METHODS

Empirical context

I examine what drives firms to race to patent by purchasing real options on patents, in response to the increased payoff attached to the prompt filing of patents. Empirically, I leverage a major in U.S. patent law, the Leahy-Smith America Invents Act (AIA), which was signed into law on September 16, 2011. In essence, AIA redefined who has the patent right to an invention. Historically, the U.S. had a FTI system, which recognizes the first to invent as entitled to the patent right, whereas the rest of the world had a FTF system, which recognizes the first to file a patent as entitled to the patent right. After 6 years of the legislative process, the U.S. decided to transition from a FTI to FTF system, effective on March 16, 2013. This transition aimed to harmonize the U.S. patent system with the systems of the other countries as well as to reduce the large volume of patent litigation and interference proceedings, which wasted resources determining who is the true inventor and thus has the patent right to the invention under a FTI system. The U.S. Congress anticipated that the implementation of a FTF system will "promote certainty in the procedures used for securing the exclusive rights of inventors to their discoveries".

Moreover, the fact that the rest of the world already had a FTF system provides us with a control group for my analyses. U.S. inventions pursuing foreign protection were less affected by AIA (since these inventions were always subject to a FTF rule both before and after AIA) and thus can serve as a control group. By contrast, U.S. inventions pursuing only domestic protection were directly affected by AIA and thus can serve as a treatment group.

In addition to a FTF system, AIA ushered in several other changes, which I report in Appendix Table B.1. For example, AIA expanded the scope of prior user rights[9] defense to include any process, machine, manufacture, or composition of matter beyond business methods. Thus, we may not know for sure whether firms' greater use of real options on patents after AIA is attributable to a FTF system or other provision changes. However, such concerns are insubstantial because it is unclear how these provision changes other than the implementation of a FTF system can alter firms' incentives to race to patent.

Data

My sample employs data from the USPTO, and consists of 484,907 U.S. "original" non-continuing utility patent applications which were filed either in a pre-AIA 12-month window (September 16, 2010-September 15, 2011) or in a post-AIA 12-month window (March 16, 2013-March 15, 2014). I exclude continuing utility patent applications because they cannot be filed as provisional applications. I further exclude a time period between the enactment and effective date of AIA in order to take account of the possibility that firms start to alter behavior during this interim period in anticipation of AIA. The sample is based on published applications as of March 5, 2016.

I then match my sample with industry concentration data from the Bureau of Economic Analysis (BEA) and with patent effectiveness (industry average) data from the CMS (Cohen et al., 2000). The industry concentration data are matched through the NAICS-USPC concordance file from the USPTO, and the patent effectiveness data are first matched through the ISIC-NAICS concordance file from the United Nations Statistics Division and subsequently through

[9] It applies where the use was at least 1 year prior to the patentee's filing date or the date the invention was disclosed to the public for the prior art exception under new Section 102(b).

the NAICS-USPC concordance file[10]. Finally, I link my sample to the standardized patent assignee name from Thomson Innovation in order to uniquely identify the firm in computing the patent citation-based measure of firm technological dominance. As a result, 79% of patents with the standardized patent assignee[11] name in my sample were matched to the organization assignee observed in the citation universe file from the USPTO.

Variables

Dependent variable

The dependent variable is a firm's *choice to buy a real option on a patent*. This choice is operationalized as an indicator variable (= 1 if a patent application was initially filed as a provisional application; = 0 if as a regular application).

Explanatory variables

Time period indicator: a time period indicator that indicates a post-AIA patent which was initially filed on or after the AIA effective date (March 16, 2013)

Invention pursuing domestic protection: a dummy variable that indicates whether a patent sought domestic protection and no foreign protection

I also include the interaction of the variables (i) and (ii), which indicates whether a post-AIA patent sought only domestic protection.

[10] This procedure was needed to map the patent technology classes (USPC) onto the corresponding industries (NAICS/ISIC).

[11] These assignees can be any type (e.g., individual, non-government organization, or government, etc.), which will be matched only to organization assignees due to limited data availability.

Industry concentration: a Herfindahl concentration index for manufacturing industries, computed as the sum of the squares of the individual sales percentages for the 50 largest firms or the universe, whichever is lower, in the industry

Patent effectiveness: the mean percentages of product and process innovations for which patent protection is considered effective in the industry (the means computed using the midpoints of the five response categories: less than 10%; 10-40%; 41-60%; 61-90%; and greater than 90%)

Technological dominance: the proportion of patent citations controlled by the firm in the citation universe of the technological space, computed as a ratio of citations received by the firm to the total patent citations received by the technology class (3-digit USPC main class) in the prior five years (September 16, 2005-March 16, 2009)

I control for the following variable:

Technology categories: the set of 8 indicator variables which represent each of the 8 international patent classification (IPC) sections a patent belongs to: (a) human necessities (13.67%); (b) performing operations, transporting (12.26%); (c) chemistry, metallurgy (7.21%); (d) textiles, paper (0.44%); (e) fixed constructions (2.25%); (f) mechanical engineering, lighting, heating, weapons (7.97%); (g) physics (29.51%); and (h) electricity (26.70%)

Table 3.1 reports the summary statistics and correlations for these variables. Panel A suggests that there are no significant correlations that are worrisome for my analyses. In Panel B I note that the mean of my explanatory variables largely remained the same after AIA for both the control and treatment groups, except for the technological dominance variable, which significantly decreased by 28.6% after AIA for the treatment group.

Methods

I employ a difference-in-differences (DID) design to examine firms' choice to buy a real option on a patent (=file a provisional as opposed to a regular application) in their race to obtain the patent right. My estimation uses linear probability models with robust standard errors. Linear probability models are better-suited to my analyses than non-linear models such as logit and probit since we are interested in the marginal effect but not in predicting probabilities. Further, when the true conditional expectation function is unknown, linear probability models tend to offer the best approximation (Angrist & Pischke, 2009).

Taken together, I estimate the following linear probability model on a DID design (Wooldridge, 2010):

$$y = \beta_0 + \beta_1 dB + \delta_0 d2 + \delta_1 dB * d2 + x'\theta + u,$$

where y is the choice to file a provisional application, $d2$ a dummy that indicates a post-AIA patent, dB a dummy that indicates the treatment group of patents pursuing only domestic protection, and x the vector of other explanatory variables. The DID estimator δ_1, the coefficient of interest, is estimated as $\widehat{\delta_1} = (\bar{y}_{B,2} - \bar{y}_{B,1}) - (\bar{y}_{A,2} - \bar{y}_{A,1})$.

RESULTS

As a preliminary step, I examine whether a change caused by AIA in the probability of buying a real option on patenting was on average different for the control and treatment groups. Figure 3.1 shows that there was a much larger increase in the use of provisionals for the treatment than control group, after AIA went into effect.

I further report the mean probability separately for large and small entities[12] in order to look for an indication of size effects. Table 3.2 reports the descriptive statistics for my dependent variable, firms' choice to buy a real option on patenting (=choice to file a provisional as opposed to a regular application)[13]. A few points are noteworthy. First, after AIA went into effect, all four groups (control-large; control-small; treatment-large; treatment-small) experienced an increase in the mean probability of filing a provisional application. The largest change was in the treatment group inventions owned by large entities (+37% from 0.214 to 0.293). The second largest change was in the treatment group inventions owned by small entities (+21% from 0.384 to 0.466). We see less change in magnitude in the control sample (+3% for large entities; +10% for small entities). In addition, provisional applications are filed more often by small than large innovators.

Then I turn to the analyses which test for my hypotheses. I control for technology categories using the dummy which indicates mechanical engineering, lighting, heating and weapons as the reference category. In Table 3.3, the significant DID estimate of 0.061 in the full sample suggests that the treatment group inventions were 7.0% (0.009+0.061=0.070) more likely to buy real options on patents after AIA, whereas the control group inventions were 0.9% more likely. The DID estimates for the small and large entities subsample analyses show that the

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[12] I use the "small_entity_indicator" variable provided by the USPTO to break down our sample to these two subsamples. This variable is a dummy equal to 1 if the applicant qualifies as a small entity, which is typically either an individual inventor, a collaboration of individual inventors, a nonprofit organization, or a company with fewer than 500 employees; and equal to 0 otherwise.

[13] The overall 7 percentage point increase in the use of a provisional application post-AIA in the treatment group is comparable to what we have seen with the AIPA in Chapter 2 of my dissertation.

marginal effect of AIA was greater for inventions owned by large than small innovators (0.069 versus 0.059). These findings support H1 that firms will be more likely to use patenting real options under a FTF than FTI system.

Robustness check

Before I test H2a, H2b, and H3, I conduct a robustness check for H1. In Figure 3.2, I visually illustrate the marginal effect of AIA on firms' use of provisional applications. While I employ the same model for the full sample as in Table 3.3, I use quarter dummies with reference to the quarter AIA went into effect, instead of the single dummy indicating post-AIA. In order to trace the effect overtime, I temporarily include patent applications filed during the interim period between the enactment and effective date, which increases the number of observations to 900,545 patent applications. The results suggest that the use of provisional applications on average increased more than 5 percentage points after AIA. This number represents a more than 18% increase relative to the pre-AIA average level of use by the treatment group in Table 3.2. This finding again confirms H1.

Next, I test for the competing hypotheses H2a and H2b by examining the coefficients on three-way interactions. Since the patent effectiveness variable is measured separately for product and process innovations in the industry, I run analyses separately and see if my results are different for these product innovation- and process innovation-based patent effectiveness measures.

In Table 3.4 Model (5; product), the three-way interaction with high concentration is insignificant in the full sample but significant in the large entity subsample. The economic significance of this coefficient in the large entity subsample indicates that a one standard deviation increase from the mean industry concentration leads to a 1.3 percentage point increase in the main effect (see Appendix Table B.2). This finding offers partial support for H2a: large firms were more likely to use real options on patents under a FTF system when in more concentrated industries. An interaction plot Figure 3.3 graphically illustrates this point. By contrast, industry concentration did not matter for small firms. Indeed, these findings jointly suggest that dominant firms in concentrated industries race to patent in order to sustain their market dominance by preempting others, supportive of Gilbert and Newbery (1982). On the other hand, although small innovators were frequent users of provisional applications (see Table 3.2), their use under a FTF system was not impacted by industry concentration. Table 3.4 Model (5; process) further suggests that the DID coefficient on the three-way interaction has the same sign as Model (5; product) while statistically insignificant.

I then move onto H3. Table 3.4 Model (5; product) indicates that the coefficient on the three-way interaction with technological dominance is negative significant in both the full sample and the large entity subsample. As reported in Appendix Table B.2, the economic significance of this coefficient suggests that a one standard deviation increase from the mean technological dominance leads to a 1.4 percentage point decrease (for the full sample; see also Figure 3.4) and a 1.1 percentage point decrease (for the large entity subsample) in the main effect. This finding shows that when others had been building on the firm's inventions to a greater extent, the firm was less likely to buy patenting real options after AIA, which corroborates H3. The technologically dominant firm seems to let others obtain patents on follow-on inventions rather than obtain the patents itself, largely interested in growing the "pie" for value appropriation. These results stay the same with the process innovation-based measure of patent effectiveness. In fact, the economic significance rises in Table 3.4 Model (5; process): a one standard deviation increase from the mean of a firm's technological dominance results in a 1.9 percentage point decrease (for the full sample) and a 1.5 percentage point decrease (for the large entity subsample) in the main effect.

Finally, I test for H4. Table 3.4 Model (5; product) suggests that the coefficient on the three-way interaction with patent effectiveness is negative significant in both the full sample and the large entity subsample. The economic significance of this result indicates that a one standard deviation increase from the mean of the industry effectiveness leads to a 2.6 percentage point decrease (for the full sample; see also Figure 3.5) and a 4.1 percentage point decrease (for the large entity subsample) in the main effect. Thus, I find no support for H4 and instead find that the opposite holds. In high-patent-effectiveness industries, the increased payoff to prompt filing as a result of AIA did not impact firms' incentives since they would race to patent anyway in the first place, given the high importance of patent protection in appropriating value from inventions. In real options terms, lower uncertainty over the value of patent protection in these industries lowers the value of patenting real options. Alternatively, this finding may suggest that firms in low-patent-effectiveness industries still race to patent by filing a provisional application, primarily driven by defensive preemption motives. Based on the economic significance of the coefficients in Appendix Table B.2, I also find that large innovators were even more likely to buy patenting real options in low-patent-effectiveness industries than small innovators (|-4.1%| versus |-2.6%|) even after controlling for industry concentration and technological dominance.

Interestingly, in Table 3.4 Model (5; process), while these results stay mostly the same with the process innovation-based measure of patent effectiveness, we see that the economic significance rises substantially. A one standard deviation increase from the mean industry effectiveness leads to a 4.0 percentage point decrease (for the full sample) and a 7.0 percentage point decrease (for the large entity subsample) in the main effect. The greater impact of the implementation of a FTF system on process than product patent effective industries may be attributed to the empirical observation that patent effectiveness is generally lower for process than product innovations (Cohen et al., 2000). Thus, patent real options may have been even more valuable in low-process-patent-effectiveness than low-product-patent-effectiveness industries.

Additional analyses

In Table B.3 of Appendix B, I further investigate how various invention attributes – the numbers of forward citations, claims, and backward citations – within the firm influence its choice to file a provisional application (relative to a regular application) by using linear probability models with assignee fixed effects. I find that these correlates of patent value (Harhoff et al., 2003; Lanjouw & Schankerman, 2004) do not generally impact the firm's use of a provisional application under a FTF system (i.e., after the implementation of AIA), except the number of forward citations for a large firm ($\beta=0.0062$, $p\text{-value}<0.05$). The likelihood of a large firm using a provisional application was greater for an invention which it perceives as potentially more valuable.

DISCUSSION AND CONCLUSION

The central proposition in this paper is that real options in patent races are more valuable under a FTF than a FTI system. Provisional applications establish patent priority at substantially lower costs than regular applications and provide firms with the right but not the obligation to file regular applications. I leverage U.S. transition from a FTI to a FTF system, implemented by

AIA, and find that firms use provisional applications as solutions to the incentives and challenges imposed by a FTF system. This finding thus supports my central proposition and provides evidence that a real options lens is important for understanding firms' patenting strategies. Given that prior research on real options in innovation focuses on the implications of a real options lens for value creation (e.g., Hurry et al., 1992; Mitchel & Hamilton, 1987; McGrath, 1997; McGrath & Nerkar, 2004; Schwartz, 2004; Schwartz & Moon, 2000), my study contributes to this body of literature by highlighting how firms seek to use real options thinking to appropriate value from innovations.

Furthermore, my contingency findings shed light on the strategic implications of the winner-take-all features of patent systems (e.g., Gilbert & Newbery, 1982; Reinganum, 1983; Tirole, 1989). I show that the strategies of all firms are not identical, and reflect key differences in technological dominance, market concentration, and patent effectiveness. My findings that the use of provisionals under a FTF system was more pronounced for firms with less technological dominance and greater industry dominance suggest that dominance in upstream and downstream spaces can have differential impacts on patent races. Firms were more likely to race to patent with real options when they were less dominant in the upstream space and when more dominant in the downstream space. These findings add novel insights to the existing literature which has not disentangled the multifaceted construct of firm dominance as an antecedent of patent races.

Surprisingly, I find that firms used patent race options more heavily under a FTF system when they were in industries with less patent effectiveness, in contrast with my expectation. This finding may reflect higher uncertainty in patent value in low-patent-effectiveness industries, which would increase the option value of provisionals (Dixit & Pindyck, 1994) and/or preemptive patenting for defensive purposes, which is arguably more prevalent in such industries

(Hall & Ziedonis, 2001). Counterintuitively, firms in low-patent-effectiveness industries by no means avoid patenting: they just seem to take a prudent approach to patenting by purchasing real options on patents, faced with high patent uncertainty as well as defensive needs for obtaining the patent right. In this regard, my findings advances prior research by to patent versus not to patent

Finally, this study also contributes to our empirical understanding of patent races by taking advantage of a natural quasi-experiment that enables robust identification of causal relationships between FTF rules and firm-level patent strategies. I employ novel data on provisionals, which I understand as an exemplar of a variety of real options available to patentees within the patent system, such as the right to withdraw applications (and preserve secrecy), the right to renew patents, the right to enforce them, and so on. These data enable us to make more accurate valuations of real options at the invention level, as called for by recent research on real options in the management field (Trigeorgis & Reuer, 2017).

My study could be improved in several ways. Due to data limitations, I am unable to observe provisionals which did not lead to the eventual filing of regular applications. Thus, I cannot study firms' exercise of options in patent races. However, the available aggregate data (i.e., the number of provisional and/or regular applications filed) will allow us to compare the likelihood of provisionals leading to the eventual filing of regular applications before and after AIA. If that likelihood increased after AIA, I may view it as indirect evidence that firms were more likely to exercise their patent race options after AIA, which substantially increased firms' payoff of prompt patent filing. I believe that these data are worth investigating as a supplementary analysis.

This study prompts further questions about whether firms' greater patent racing is the manifestation of their inventing more versus filing more. Although I have not examined these issues in my study, I believe that the latter is a more plausible story, assuming that only payoffs attached to prompt patent filing was altered and nothing else during my sample period. Nevertheless, empirically investigating whether that is the case may facilitate better understanding of the important phenomenon in economics of innovation. Moreover, even though this study broadly examines industry, technology, and appropriability conditions under which firms race to patent, we still know little about what exactly motivates these firms to rush to file under a FTF system. For example, it can be either preemptive or defensive motives that can drive firms to race to patent (e.g., Blind et al., 2006; Cohen et al., 2000). In order to understand these motives perceived by firms, some qualitative studies of U.S. firms (on their patenting strategies after AIA) can be useful and will generally inform research in not only appropriability strategy but also law and economics.

In summary, my study examines what drives firms to use provisional (as opposed to regular) applications as real options in patenting, in their race to patent. I leverage the AIA, a recent major change in U.S. patent law, and show that the patenting real options are more valuable under a FTF than FTI system and that this effect also depends on technological dominance, market concentration, and patent effectiveness. My study contributes to the appropriability strategies literature – in particular, research on real options in innovation – as well as innovation research in industrial organization.

TABLES AND FIGURES

Table 3.1: Summary statistics and correlation table (n= 484,907 patent applications)
Panel A

	Variable	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)
(1)	Provisional	0.177	0.382	0.000	1.000	1.000				
(2)	Industry concentration	112.366	55.402	9.000	555.400	-0.036	1.000			
(3)	Technological dominance	0.011	0.033	0.000	1.000	-0.059	-0.017	1.000		
(4)	Patent effectiveness (product)	34.625	3.827	18.260	40.673	0.003	0.142	-0.009	1.000	
(5)	Patent effectiveness (process)	21.978	2.552	16.400	29.053	0.030	0.034	-0.042	0.615	1.000

Panel B

	Pre-AIA international (n= 186,931 patent applications)				Post-AIA international (n= 185,833 patent applications)			
	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Industry concentration	112.498	53.682	9.000	555.400	113.389	55.934	9.000	555.400
Technological dominance	0.011	0.033	0.000	1.000	0.009	0.030	0.000	1.000
Patent effectiveness (product)	34.739	3.903	18.260	40.673	34.602	3.947	18.260	40.673
Patent effectiveness (process)	22.120	2.749	16.400	29.053	21.998	2.641	16.400	29.053
	Pre-AIA only domestic (n= 54,223 patent applications)				Post-AIA only domestic (n= 57,920 patent applications)			
	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Industry concentration	109.717	57.735	9.000	555.400	110.929	57.021	9.000	555.400
Technological dominance	0.021	0.042	0.000	1.000	0.015	0.036	0.000	0.800
Patent effectiveness (product)	34.481	3.446	18.260	40.673	34.447	3.461	18.260	40.673
Patent effectiveness (process)	21.719	1.982	16.400	29.053	21.665	1.883	16.400	29.053

Table 3.2: Descriptive statistics (means) for use of a provisional (n= 484,907 patent applications)

		Large entity		Small entity	
		Pre-AIA	Post-AIA	Pre-AIA	Post-AIA
International protection	Mean	0.115	0.119	0.204	0.224
	Std. err.	(0.001)	(0.001)	(0.002)	(0.002)
	No. obs.	153,111	151,815	33,820	34,018
Domestic protection		0.214	0.293	0.384	0.466
		(0.002)	(0.002)	(0.003)	(0.004)
		32,483	38,378	21,740	19,542

Table 3.3: Linear probability DID results for use of a provisional

	Model (1)		
	Full sample	Small entity subsample	Large entity subsample
Only domestic protection	0.150***	0.180***	0.104***
	(0.002)	(0.004)	(0.002)
Post-AIA	0.009***	0.019***	0.006***
	(0.001)	(0.003)	(0.001)
Post-AIA * Only domestic protection	0.061***	0.059***	0.069***
	(0.003)	(0.006)	(0.003)
Constant	0.104***	0.158***	0.090***
	(0.002)	(0.005)	(0.002)
Technology category dummies	Y	Y	Y
Observations	484,907	109,120	375,787

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.4: Linear probability DID results for use of a provisional

	Model (5; product)		Model (5; process)	
	Full sample	Large entity subsample	Full sample	Large entity subsample
Only domestic protection	-0.082**	-0.096**	-0.474***	-0.545***
	(0.036)	(0.041)	(0.039)	(0.047)
Post-AIA	-0.034***	-0.024**	-0.023*	-0.019
	(0.012)	(0.012)	(0.012)	(0.013)
High concentration	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
High patent effectiveness	-0.000	0.001**	-0.002***	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)
High technological dominance	-0.332***	-0.259***	-0.345***	-0.266***
	(0.022)	(0.021)	(0.022)	(0.021)
Post-AIA * Only domestic protection	0.278***	0.394***	0.390***	0.625***
	(0.048)	(0.056)	(0.053)	(0.066)
Post-AIA * High concentration	-0.000	-0.000**	-0.000	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Only domestic protection * High concentration	-0.001***	-0.001***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Post-AIA * Only domestic protection * High concentration	0.000	0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Post-AIA * High patent effectiveness	0.001***	0.001***	0.002***	0.002***
	(0.000)	(0.000)	(0.001)	(0.001)
Only domestic protection * High patent effectiveness	0.009***	0.009***	0.031***	0.034***
	(0.001)	(0.001)	(0.002)	(0.002)
Post-AIA * Only domestic protection * High patent effectiveness	-0.007***	-0.011***	-0.016***	-0.027***
	(0.001)	(0.002)	(0.002)	(0.003)
Post-AIA * High technological dominance	0.174***	0.188***	0.182***	0.194***
	(0.033)	(0.032)	(0.033)	(0.032)
Only domestic protection * High technological dominance	-1.559***	-1.295***	-1.427***	-1.190***
	(0.069)	(0.064)	(0.067)	(0.062)
Post-AIA * Only domestic protection * High technological dominance	-0.426***	-0.323***	-0.569***	-0.449***
	(0.095)	(0.089)	(0.094)	(0.089)
Constant	0.096***	0.057***	0.135***	0.095***
	(0.009)	(0.009)	(0.010)	(0.011)
Technology category dummies	Y	Y	Y	Y
Observations	299,141	260,193	299,141	260,193

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 3.1: Mean use of a provisional per month

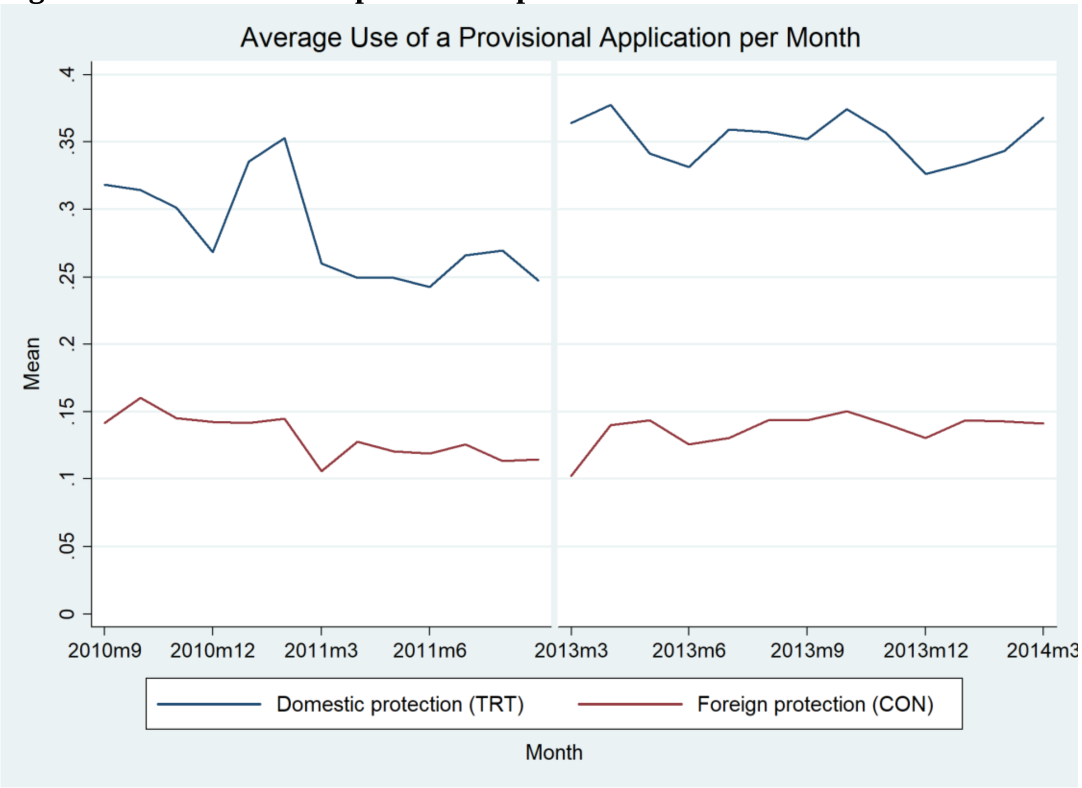


Figure 3.2: Linear probability DID coefficients in each quarter (n=900,545 applications)

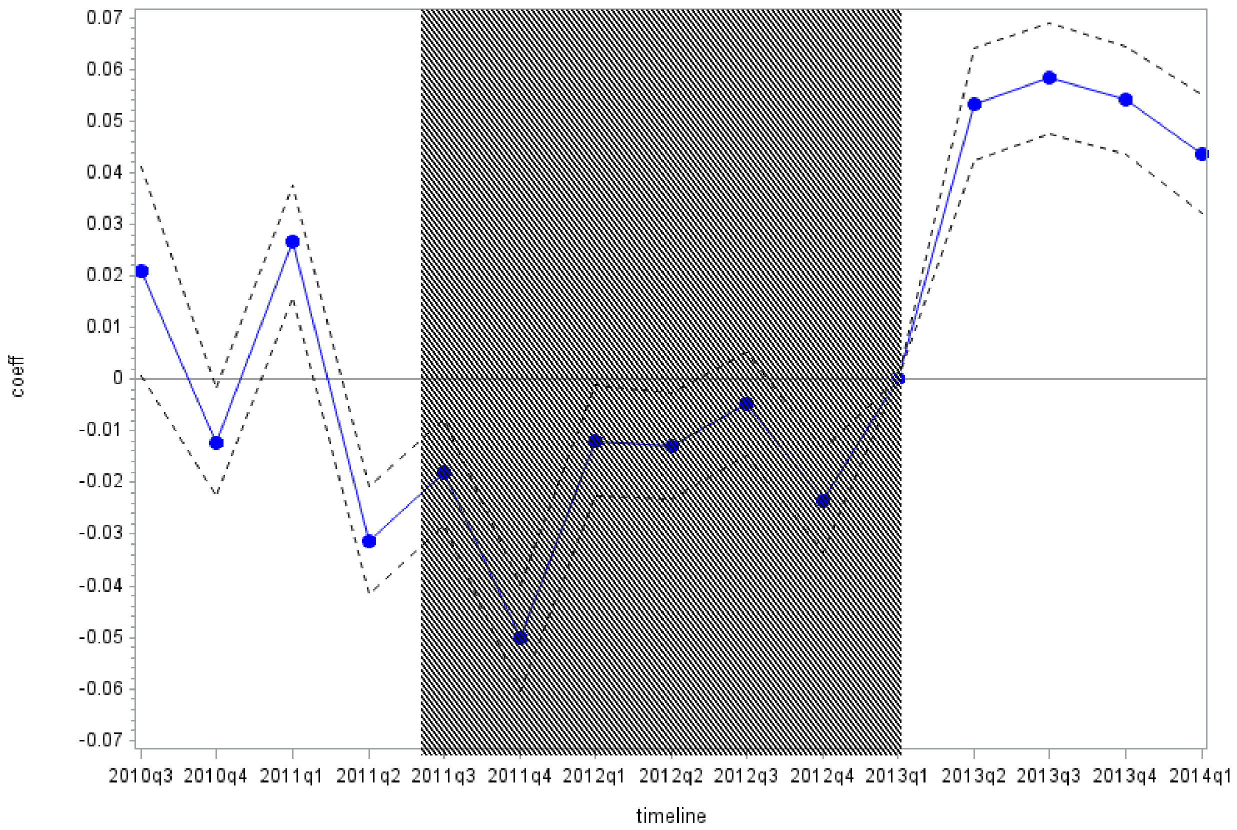


Figure 3.3: Interaction effects on use of a provisional for industry concentration (large entity subsample)

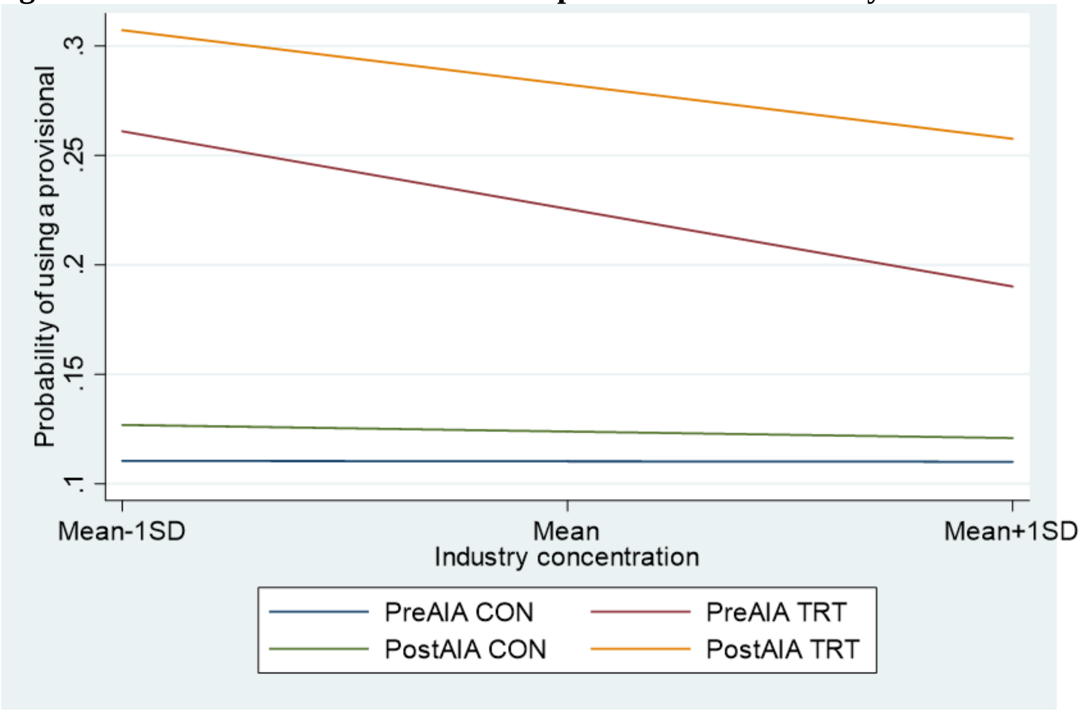


Figure 3.4: Interaction effects on use of a provisional for technological dominance

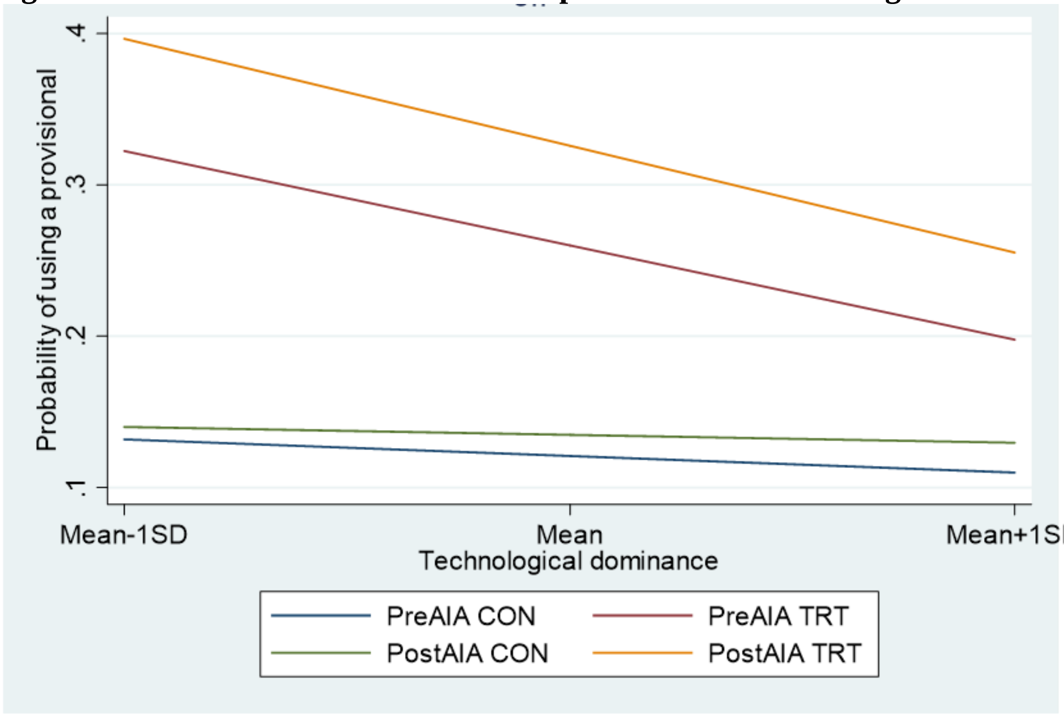
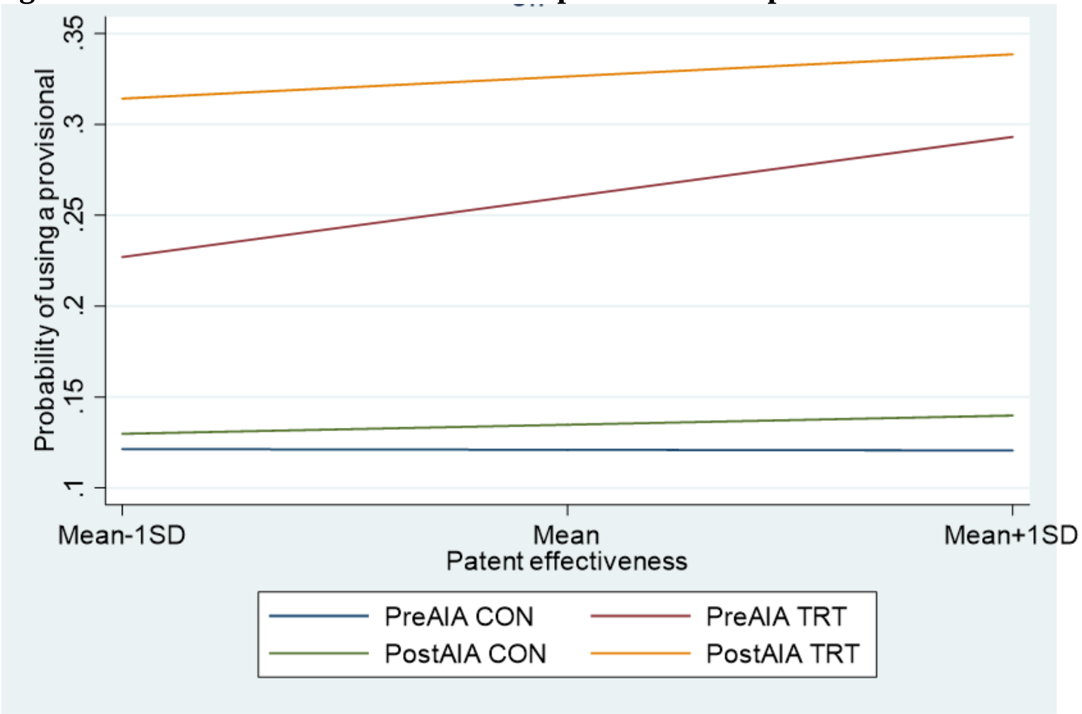


Figure 3.5: Interaction effects on use of a provisional for patent effectiveness



CHAPTER 4: WHEN DO PATENTEES PRESERVE REAL OPTIONS IN PATENT TERM EXTENSION?: EVIDENCE FROM THE PATENTING "SURGE" OF 1995

INTRODUCTION

Patent term – the length of patent protection conferred to patentees – has been a significant subject among policymakers as well as law and economics scholars studying the relations between the patent system and innovation (e.g., Abrams, 2009; Devlin & Sukhatme, 2009; Lemley, 1994). In the past few decades we have seen the U.S. continuously making changes to how long it will protect patentees' exclusive rights to inventions. A quintessential policy and research question has mostly been what should be the optimal patent term. Much of scholarly work has focused on understanding industry differences which will make some industries desire a longer patent term (e.g., Jorde & Teece, 1989; Lemley, 1994; Levin et al., 1987; Sukhatme & Cramer, 2014).

However, how various invention attributes may influence firms to pursue a longer patent term has received little scrutiny. Examining the invention-level covariates of their preferences is important since it sheds light on value appropriation opportunities over the life span of the patent. Thus, managers can strategize differently for inventions with different expected life spans. For example, for inventions which are likely to create value for a longer time, managers can take a risk to develop co-specialized assets to appropriate the value, which they would not for those inventions that are likely to live shorter. Furthermore, policymakers can be better informed of *who* may be interested in (or potentially benefit from) obtaining a longer patent term, in introducing future reforms to the patent system.

Prior research recognizes that the importance of patent term varies by industry. Depending on the industry, the marginal value of an extra month added to the end of the term for a patent (which will expire in 15 years) is worth from zero to millions of dollars (Crouch, 2015). These differences may arise from variation in the technology life cycle (Eurek, 2003; Lemley, 1994; Sukhatme & Cramer, 2014). For example, pharmaceuticals cannot appropriate value from inventions until Food and Drug Administration (FDA) approval, which often happens much later than patent issuance. While these firms have a much shorter "effective patent term" (i.e., time between commercialization and patent expiry), their inventions tend to create value for a longer period of time (even after patent expiry) (Eurek, 2003). Thus, pharmaceuticals may desire a longer patent term than other industries. On the other hand, firms in computers and communications may not be as interested in obtaining a longer patent term because of the fast pace of technology development, which makes inventions obsolete in the early years of patent term.

For the purpose of mitigating concerns arising from industry differences, the U.S. Congress has amended patent law several times. Among others, the Hatch-Waxman Act of 1984 introduced the new provisions of patent term extension to compensate for the commercialization delays of drugs and medical inventions resulting from the required FDA approval procedures. Given that policymakers should design patent term such that it incentivizes innovation and does not permit excess monopoly returns (Devlin & Sukhatme, 2009; Mazzoleni & Nelson, 1998), studying firms' preferences for the length of patent term based on invention as well as industry attributes casts useful light on how that can be achieved.

I examine how various invention attributes impact firms' preferences for the length of patent term by leveraging the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS), which was enacted on December 8, 1994 and went into effect on June 8, 1995. As a result of this change in U.S. patent law, the U.S. patent term is calculated 20 years from earliest filing as opposed to 17 years from issuance under the old rule. This empirical context provides a unique opportunity to study my research question because firms that filed a patent during the interim period (from the enactment through effective date) were given whichever longer of the two patent terms under the old and the new rule. The availability of this option indeed caused a surge of patent applications filed in the days leading up to the transition. The patent office reported that more than 50,000 patent applications were received in the 9 days before the TRIPS effective date (Montalvo, 1996), which was 10 times greater than a typical rate of about 5,000 applications. I understand firms' filing of a patent immediately before the effective date as their choice to buy a real option in patent term extension, and examine how various invention attributes drove this choice. Despite my a priori, I take an exploratory approach to my empirical analyses.

INSTITUTIONAL DETAILS: TRIPS

The Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) was negotiated as part of the Uruguay round of the General Agreement on Trade and Tariffs (GATT), which created the World Trade Organization (WTO). TRIPS incorporated intellectual property (IP) law into the international trade system by introducing new significant requirements to the existing requirements under the Paris and the Berne Convention (WTO, 2017), and is viewed as the most comprehensive multilateral agreement on IP by far. TRIPS stipulated minimum standards for national IP law that must be enforced across WTO member countries, but provided them with leeway to determine the most appropriate ways to implement these standards in their own legal systems and practice.

With TRIPS, many countries also entered into bilateral agreements to implement some higher standards of IP law. The U.S. and Japan decided on a bilateral agreement in order to address concerns regarding each other's patent system (Lemley, 1994). As a result, the U.S. had to transition from the 17-years-from-issuance patent term to the 20-years-from-(earliest) filing patent term. Patent term in the U.S. was ordinarily measured 17 years from the date of patent issuance, but as TRIPS was signed into law on December 8, 1994 and went into effect on June 8, 1995, U.S. patent term is measured 20 years from the earliest filing date (i.e., priority date[14]). This new 20-year patent term implies that if the interval of time between the earliest filing date and the patent issuance date is greater than three years, for that invention the patentee will be given a patent term shorter than what it would have been under the old rule. Therefore, firms have lower incentives to delay the issuance of patents under the new rule.

Proponents of TRIPS argued that the new rule would prevent notorious "submarine patenting", whereby patent applicants deliberately delay patent issuance in order to monitor rivals developing technologies and claim these technologies as their own in the patent application, which unjustly holds up the rivals (Lemley & Moore, 2004; Merges et al., 2003). According to the proponents, TRIPS will discourage the use of "continuing" patent applications, derivative applications claiming priority to earlier applications and recognized as the key vehicle of practicing submarine patenting (Lemley & Moore, 2004). TRIPS provides disincentives to keep amending claims through continuing applications since doing so will shorten patent term, the time of the exclusive right to appropriate value from an innovation.

By contrast, opponents of TRIPS, including Representative Dana Rohrabacher and Senator Bob Dole – who introduced a bill to restore the old 17-year rule –, contended that the

[14] The priority date is the earliest U.S. patent filing date from which the patent derives its priority over other patent applications. For patent applications (specifically claims within the patent) that derive priority through the filing of continuation or divisional applications, the priority date is the filing date of the earliest such application.

new 20-year rule will adversely affect U.S. patentees by effectively shortening their patent term. For example, firms may have lower incentives to engage in R&D since the new rule will presumably result in a decrease in royalties from inventions, which can be particularly consequential for small innovators and universities (Rohrabacher & Crilly, 1995). According to these opponents, it is only foreign and multinational firms that will benefit from the new rule because they will not have to pay as large royalties to U.S. patentees as before.

In its implementation of the new 20-year patent term, the U.S. provided a transition rule, where firms that filed a patent during the interim period (from the enactment through effective date) were given whichever longer of the two patent terms under the old and the new rule. The availability of this option resulted in a surge of patent applications filed in the days leading up to the transition. The patent office reported that more than 50,000 patent applications were received in the 9 days before the TRIPS effective date (Montalvo, 1996), which was 10 times greater than a typical rate of about 5,000 applications. The empirical investigation of such striking revealed preference unveils some drivers of firms' buying real options to extend patent term. Figure 4.1 graphically illustrates this surge of patent applications leading up to the implementation of the new 20-year patent term.

CONCEPTUAL DEVELOPMENT

I explore invention attributes that may affect a firm's choice to buy an option to extend patent term (i.e., file a patent before the new 20-year patent term comes into force).

Expected prosecution time:

Patent prosecution is a back-and-forth process between the applicant and the examiner (e.g., Carley et al., 2015; Lemley & Moore, 2004). Once a firm files a patent, an examiner reviews it to determine whether it meets the patentability criteria. If the examiner rejects some of the claims drafted in the application, the firm responds by further arguing the invention's patentability or by amending these claims to narrow the scope of protection. Then the examiner makes a final determination. Although it may be difficult to accurately foresee how long it will take to have patents finally granted, given the nature of prosecution processes (consisting of both applicant- and examiner-induced delays), firms can form expectations to some extent based on their prior experiences in the technology field. While all firms may prefer preserving the right to choose between the two patent terms, it will particularly be those firms in anticipation of longer delays – and thus the greater likelihood of losing patent term under the new rule – who have greater incentives to file before the new 20-year patent term comes into force.

Patent prosecution uncertainty:

Because of how the prosecution system works, when firms enter into the patenting process, they are faced with uncertainty in having a patent granted at a point in time consistent with their anticipation. Although firms can form expectations to some extent on how long patent prosecution will take based on their prior experiences in the field, patents can be granted much earlier or later, or finally disapproved depending on the examiner and invention attributes etc. they are dealing with. Unlike the old 17-year patent term, the new 20-year patent term presents significant challenges to firms because delays caused by examiners as well as themselves will directly reduce patent life they can capitalize on. Because these delays largely cannot be foreseen at the outset, firms may choose to buy options to extend patent term. Moreover, if firms perceive the technology to be in an area in which their expectation of prosecution time has historically been erroneous to a greater extent, they may be more likely to buy options to extend patent term for that technology.

Continuations (continuations, continuation-in-parts, and divisionals):

Whether a patent is filed as a "continuing" or a non-continuing "original" application may impact a firm's choice to buy options to extend patent term. Inventors are allowed to start over the patent prosecution process by filing continuing applications based on earlier filed applications which did not lead to issuance (Lemley & Moore, 2004). Because continuing applications claim priority to the earlier filed applications, they are more likely to lose patent term under TRIPS. Therefore, firms will be more likely to file these applications before TRIPS comes into force. In the U.S. continuing applications take one of the following three forms: continuation, continuation-in-part, and divisional. The different types of continuing applications are filed for different reasons (Hegde et al., 2009), and thus may lead to differential likelihoods of firms purchasing options to extend patent term.

Priority lapse:

Priority lapse, how much time has passed since the earliest filing date (i.e., priority date) before a firm files the focal patent application claiming priority to that earlier application, may be another important factor that affects the firm's choice to buy options to extend patent term. I expect that firms will be more likely to file before TRIPS comes into force if the application will claim priority to much older applications because that application will likely lead to shorter patent term. Furthermore, applications which claim priority to much older applications may plausibly be the ones that are more valuable for the firm's business given the firm's continuing commitment to securing the property right on those inventions. If the firm has an important strategic stake in those inventions, it will be more likely to buy options to extend patent term for them.

Next, I expect that the more valuable the invention, the more likely that a firm chooses to buy options to extend patent term. The construct of invention value is positively correlated with the following three variables, which are used extensively to operationalize it in empirical research: forward citations, backward citations, and invention breadth.

Forward citations:

Prior research extensively uses the number of forward citations, defined as the number of citations received by the patent from subsequent patents, as a proxy for the value of an invention (e.g., Abrams et al., 2013; Hall et al., 2005). The greater number of citations the focal patent receives from subsequent patents implies that these patents build on the focal patent to a greater extent. Thus, this forward-citation-based proxy for invention value conceptually indicates how impactful the focal invention is to subsequent inventions given the cumulative nature of innovation processes (e.g., Scotchmer, 1991).

Backward citations (patent references, self-(patent) citations, non-patent references):

The number of backward citations, the number of citations made by the focal patent to prior patents, is used as another proxy for invention value (e.g., Harhoff et al., 2003). I understand the greater number of citations made by the patent to prior patents as indicating that the invention builds on knowledge from prior patents to a greater extent. The rationale is consistent with prior research which suggests that firms innovate by recombining existing knowledge (Carnabuci & Operti, 2013; Katila & Ahuja, 2002), which creates greater economic value (Kaplan & Vakili, 2015).

In patent applications, firms may cite not only prior patents but also prior non-patent references, namely scientific publications such as presentations at conferences and symposia, and peer-reviewed journals. Since inventions building on patent references (“commercial science”) and non-patent references (“open science”) can have different characteristics (e.g., Mukherjee & Stern, 2009; Murray & Stern, 2007; Stokes, 1997), I expect that these two types of inventions may result in the differential likelihoods of buying options to extend patent term. Further, I also take account of self-citations, citations made by the focal patent to prior patents owned by the same patentee. The proportion of self-citations reflects the extent to which the patentee builds on his own invention, and may represent the patentee’s competitive position in the technology (Hall et al., 2005; Trajtenberg et al., 1997). I expect that the greater the proportion of self-citations in the total backward patent citations, the more valuable options to extend patent term for the protection of the invention which is of strategic importance.

Invention breadth:

The breadth of an invention reflects how broadly applicable is the invention across different technology categories. A more broadly applicable invention (e.g., as a result of basic research) may create greater value for society by spurring the greater number of follow-on inventions for a long time (e.g., Trajtenberg et al., 1997). Thus, I expect that the more broadly applicable the invention is, the more likely that a firm seeks longer patent protection for that invention. Given the cumulative nature of innovations (e.g., Gandal & Scotchmer, 1993; Scotchmer, 1991; Trajtenberg et al., 1997), firms at the technology frontier that spur a number of follow-on innovations by others may continue to appropriate value from their own innovations during the patent term in forms of licensing payments from others etc.

Technology categories:

Firms' choice to buy options to extend patent term can be driven by the technology field of their inventions. For example, pharmaceuticals typically appropriate greater returns from their innovations later towards the end of the patent term given the lengthy processes of clinical trials and regulatory approvals (WSJ, 2012), which must be cleared before commercialization, as well as the relatively slow pace of the industry. Furthermore, these firms rely heavily on patents as their primary appropriability mechanisms (e.g., Anton et al., 2006; Henderson & Cockburn, 1994). Therefore, pharmaceuticals may plausibly have greater incentives to buy options to extend patent term for the protection of their inventions than firms in other industries. By contrast, innovations in computers and communications, subject to higher risks of technological obsolescence and weak patents (especially in software) may have less incentives to pursue options in patent term extension.

DATA AND METHODS

In my investigation of who prefers to buy options to extend patent term, I examine who were the ones that caused the striking surge of patent filing immediately before the effective date of TRIPS. Specifically, I uncover the covariates of firms' decision to file patent applications during the "surge period" prior to the TRIPS effective date relative to the period immediately following it. I estimate the probability that a patent was filed during the surge period (relative to the period immediately following it) by employing logit choice models, conditional on invention attributes.

Data

My sample consists of 24,189 U.S. utility patent applications filed one week before through two weeks after the TRIPS effective date June 8, 1995, which issued patents by the end of 2006. I match my sample to Compustat firms using the USPTO-Compustat correspondence file provided by NBER (Bessen, 2009).

Dependent variable

Choice to file before TRIPS

An indicator variable equal to 1 if the patent was filed before the TRIPS effective date and 0 if on or after.

Explanatory variables

Expected prosecution time:

I compute realized prosecution time (= time between the application and issuance dates in days) for each patent in a prior sample of patents filed within five years before the TRIPS enactment date. I then regress the realized prosecution time on technology category dummies and yearly trend. Finally, I use the estimated OLS coefficients to compute expected prosecution time $\hat{y}$ for the patents in my analysis sample.

Patent prosecution uncertainty:

I obtain residuals û from the OLS equation estimated earlier based on the prior sample of patents. Then I compute the standard deviation of û at the art unit[15] level, and link this measure to my analysis sample by the art unit. This measure represents variation in prosecution time driven by unexpected factors such as examiner-induced delays, and proxies patent prosecution uncertainty.

Continuations (continuations, continuation-in-parts, and divisionals):

Three dummies indicate whether the patent is a continuation, continuation-in-part, or divisional.

Priority lapse:

I measure priority lapse by the interval of time in days between the priority date and the application date of the patent.

Forward citations:

The number of citations received by the patent from subsequent patents. These forward citations data are subject to truncation bias, where a younger patent tends to receive fewer citations than an older patent. I address this issue by dividing the number of citations observed as of 2014 by the year-technology category average number of citations.

Backward citations (patent references, self-(patent) citations, non-patent references):

[15] Art units are examination groups which the USPTO assigns to examine patent applications covering particular technology areas. The assignment to a specific art unit affects patent prosecution time through the backlog of applications in the art unit, the nature of objections raised by the examiner (that works in the art unit), and the difficulty of overcoming objections etc.

Citations the patent makes to prior patent and non-patent references are measured separately. The citations made to patent references are further divided into self-citations (whereby the patentee cites a patent owned by himself) and non-self-citations (whereby the patentee cites a patent owned by others). I measure self-citations by the proportion of self-citations in the total citations made by the patent to prior patent references.

Invention breadth:

I measure invention breadth by the number of international patent classifications (IPCs) to which the patent belongs.

Technology categories:

A set of 6 dummies indicate each of the following technology categories to which the patent belongs: chemical (20.10% of my sample); computers and communications (15.78%); drugs and medical (26.06%); electrical and electronic (13.97%); mechanical (11.52%); others (12.56%). This aggregate classification scheme has been created by Hall et al. (2001) based on the more than 500 USPTO technology classes and is available through NBER.

Table 4.1 reports the summary statistics and correlations for my variables. Some patterns are noteworthy regarding firms' use of continuing applications. Since continuing applications by definition claim priority to earlier applications (either partially or fully), they are positively correlated with priority lapse to a moderate degree (ρ=0.567). Continuing applications can also take the forms of continuation, continuation-in-part, and divisional, and thus are positively correlated with these choices. In addition, because these choices are substitutive to one another, they are negatively correlated with one another. Overall, I do not see significant correlations in my variables which may raise concerns for my analyses.

Method

In my analyses of what drives firms to buy options to extend patent term by filing a patent before (relative to after) the TRIPS effective date, I employ the following logit model, in which Y represents the choice, and X the set of explanatory variables. I cluster standard errors by the patent assignee.

$$\mathrm{Prob}(\mathrm{Y} = 1|X) = \frac{\exp(X'\beta)}{1 + \exp(X'\beta)}$$

RESULTS

Table 4.2 shows the impact of invention attributes on firms' choice to file a patent before the new 20-year rule came into force. First, the coefficients on technology category dummies suggest that chemical, and drug and medical firms were more likely to buy options to extend patent term (Model (5) $\beta=0.2231$, $p\text{-value}<0.05$; $\beta=0.9418$, $p\text{-value}<0.01$). The marginal effects of these technology categories indicate that the predicted probabilities increase by 1.34 percentage points for chemical firms and 5.66 percentage points for drugs and medical firms. By contrast, the coefficients on computers and communications, and electrical and electronic innovations were statistically insignificant. These results are consistent with my expectation that firms will be more likely to value patent term extension when they are in industries in which returns from innovations cannot be appropriated until later towards the end of the patent term and slow-moving industries to which stronger patent protection is conferred.

Second, firms were more likely to buy options to extend patent term for continuing relative to original applications (Model (5) $\beta=0.9471$, p-value<0.01). The marginal effect indicates that the predicted probabilities increase by 5.69 percentage points for continuing applications. Because the new 20-year patent term is measured from the earliest filing date of a patent, firms plausibly chose to file continuing applications before rather than after the new rule came into force as these applications by definition have earlier filing dates than original applications and thus are subject to a greater loss of patent term. We can understand these results in conjunction with a motivation for this patent term transition, which was to "end the abuse of continuations[16]" (Lemley & Moore, 2004). Furthermore, I find that firms' choice to buy options to extend patent term was driven differentially by the different types of continuing applications. My results suggest that divisionals and continuations were more likely to be filed before the legislative transition (Model (5) $\beta=1.7235$, p-value<0.01; $\beta=0.5505$, p-value<0.01) whereas continuation-in-parts were not. We can make sense of these findings based on whether firms are allowed to add new subject matter (thus new claims) when filing the different types of continuing applications. Since the entire set of claims in divisionals and continuations must claim priority to earlier filed applications, they are the ones that were more likely to be subject to a greater loss of patent term under the new 20-year rule and thus be filed before the new 20-year rule came into force. By contrast, continuation-in-parts claim new subject matter and establish their own filing date for the new claims, and were plausibly not going to be as affected by the new 20-year rule as the others.

Third, my results suggest that citations are indeed interesting drivers of firms' choice to buy options to extend patent term. The numbers of both forward and backward citations indicate

[16] Continuations created many problems such as delaying patent issuance (which increases insecurities for competitors), wearing down examiners, and submarine patenting (Lemley & Moore, 2004).

that the greater the value of the invention, the more likely that firms will choose to buy options to extend patent term (Model (5) β=0.0003, p-value<0.05; β=0.0119, p-value<0.01). A one standard deviation increase in the mean number of backward citations leads to a 2.04 percentage point increase in the probability of filing before the new 20-year rule came into force, which is higher than the economic significance of forward citations 0.38 percentage points. If the invention is potentially more profitable, inferred from these measures (e.g., Harhoff & Reitzig, 2004; Lanjouw & Schankerman, 2001; Trajtenberg, 1990), the firm may plausibly choose to appropriate returns from the invention longer. Moreover, firms were more likely to buy options in patent term extension for inventions which draw on open science (Model (5) β=0.0334, p-value<0.01). A one standard deviation increase in the mean number of backward non-patent citations leads to a 3.98 percentage point increase in the predicted probability. Given that open science positively impacts the potential for long-term technological advance (e.g., Adams, 1990; Mansfield, 1972), inventions building on open science may create value for a longer time. However, to my surprise, I find no evidence that firms will choose to buy options in patent term extension for inventions which build on their own prior inventions. The statistically insignificant coefficient on self-citations suggests that a firm's strong competitive position in the invention (Hall et al, 2005) does not matter for the choice. Taken altogether, we can infer that a firm will value a longer patent term when the invention is valuable to the world and not necessarily when the invention is valuable to the firm itself.

Lastly, I find the broader the invention (i.e., the greater the number of potential application areas), the more likely that a firm will choose to buy options to extend patent term (Model (5) β=0.0886, p-value<0.05). A one standard deviation increase in the mean invention breadth leads to a 0.34 percentage point increase in the predicted probability. This finding can be understood jointly with my earlier findings on invention value measured by citations.

Next, I turn to Table 4.3, which reports the impact of patent prosecution attributes on firms' choice to buy options to extend patent term. In this analysis, I do not separately include technology category dummies because they are captured by expected prosecution time by design. This model assumes that technology categories ultimately impact firms' choice to buy options in patent term extension through their impact on firms' expectation of prosecution time. Consistent with my expectation, I find that a greater expected prosecution time led to the greater likelihood of firms filing before the new 20-year rule came into force (Model (12) $\beta=0.0013$, $p\text{-value}<0.01$). A one standard deviation increase in the mean expected prosecution time leads to a 0.71 percentage point increase in the predicted probability. As firms anticipate that the patent will take longer to issue, they may take out options in patent term extension, which enable them to compensate for a potential loss of patent term under the new rule.

Furthermore, not only was expected prosecution time an important driver for firms to buy options in patent term extension but also patent prosecution uncertainty was. Firms seeking to patent an invention at an art unit which had historically had greater variation in prosecution time were more likely to buy options to extend patent term (Model (12) $\beta=0.0005$, $p\text{-value}<0.01$). A one standard deviation increase in the mean patent prosecution uncertainty leads to a 0.67 percentage point increase in the probability of filing before the new 20-year rule came into force. This finding is consistent with real options theory that greater uncertainty increases the option value. In my context, the option value increases when firms' *ex ante* evaluation of the prosecution process is likely to be more divergent from the actual process. Taken together, my findings imply that firms in anticipation of a long prosecution time and in the face of high prosecution uncertainty were going to be the ones that would find options in patent term extension especially valuable.

While the impact of the other variables on firms' choice to buy options in patent term extension largely stays the same as we have seen earlier with technology category dummies included, I find that invention value measured by the number of forward citations does not matter in my models in which the patent prosecution variables are included. I currently do not have a clear explanation for this finding given the low correlations between the number of forward citations and the two patent prosecution variables (see Table 4.1 ρ=0.098; ρ=-0.072).

Additional analyses

In Table C.1 of Appendix C, I examine firms' choice to buy options in patent term extension by using models that do not include the expected prosecution time variable. These models allow me to examine the effects of patent prosecution uncertainty and industry simultaneously. Since the expected prosecution time variable has been created based on technology category dummies and yearly trend, it causes a multicollinearity problem when the technology category dummies are jointly included in models. In these models, I also take a natural log of the priority lapse variable to adjust for its skewness. I find that the results largely stay the same as what we have seen earlier in Tables 4.2 and 4.3. The effect of priority lapse (logged) becomes insignificant in all models, with the continuing application and its type dummies are controlled for.

Given the high explanatory power of the continuing application in all models, I next investigate firms' choice to file before the new 20-year rule separately for original and continuing applications. In Table C.2, I find that patent prosecution uncertainty matters for both original and continuing applications. However, when the various citations variables are included, patent prosecution uncertainty matters less for original applications, which suggests that these patent value correlates are strongly related to prosecution uncertainty for original applications. Interestingly, patent prosecution uncertainty continues to be highly significant for continuing applications in firms' choice to buy options in patent term extension, with the patent value correlates included.

DISCUSSION AND CONCLUSION

In highlighting the impact of various invention attributes on firms' choice to pursue a longer patent term, my paper contributes to the literature in IP and appropriability strategies. My findings suggest that options to extend patent term were valuable for industries in which technology pace is slow and patent protection is strong, such as chemical and drugs and medical industries. This finding implies that the value distribution of patent term indeed differs by industries, in support for the idea that different industries may need different patent term (e.g., Lemley, 1994; Levin et al., 1987; Scherer, 1980). In addition, options in patent term extension were more valuable for inventions that were potentially more profitable. This finding provides counterevidence to the proposition that value appropriation for significant inventions takes place relatively early in their patent term (e.g., Nordhaus, 1969; Scherer, 1980). Firms' revealed preference suggests that value appropriation for significant inventions happens long term and extending patent term for these inventions adds value to business. Furthermore, because the new 20-year patent term is measured from the earliest filing date, continuing patent applications (especially, those which add no new subject matter and thus in their entirety claim priority to earlier applications) were more likely to benefit from such options.

This paper also has theoretical implications for research on real options in innovation. My findings shed light on when firms take a real options approach to appropriating value from their inventions as long as possible. Consistent with real options theory, which recognizes uncertainty as an important driver of the option value (e.g., Dixit & Pindyck, 1994; Li et al., 2007; Trigeorgis & Reuer, 2017), I found that uncertainty in patent prosecution increased the likelihood of firms purchasing options in patent term extension. This finding provides new insights into firms' use of real options for value appropriation purposes beyond prior research which focuses on real options in value creation (e.g., Hurry et al., 1992; Mitchel & Hamilton, 1988; McGrath, 1997; McGrath & Nerkar, 2004).

My findings have further implications for law scholars and policymakers. Despite a large body of research examining industry attributes which may justify the implementation of industry-specific patent term (e.g., Lemley, 1994; Levin et al., 1987; Scherer, 1980), other factors which drive firms to delay the end of their exclusive rights to inventions have received scant attention. To my knowledge, this study is the first to provide extensive empirical explorations of these factors. While patent policy designs patent term such that it incentivizes innovation and at the same time prevents excessive monopoly (Devlin & Sukhatme, 2009; Mazzoleni & Nelson, 1998), my findings provide policymakers with useful insights into who may be interested in obtaining (and arguably deserve) a longer patent term than others. In fact, the U.S. has been ushering in a series of major and/or minor revisions to calculating the length of patent protection. The Hatch-Waxman Act of 1984 implemented patent term extension (PTE) and extended patent term to compensate for *commercialization* delays due to regulatory approval. The American Inventors Protection Act of 1999 implemented patent term adjustment (PTA) and extended patent term to compensate for *PTO-induced* delays, in order to mitigate concerns that arise under the new 20-year rule.

Furthermore, this study helps managers to strategize their innovation strategies by approximating what will be the life span of their patents. For example, for inventions that are likely to live longer, managers may renew the patent right on them by paying multi-staged fees (at 3.5, 7.5, and 11.5 years from issuance) and plausibly envisage long-term value appropriation strategies (e.g., investment in co-specialized complementary assets). Firms can differentiate value appropriation strategies for these inventions against others. Moreover, my finding that firms sought to extend patent term for inventions building on open science suggests that firms perceive securing stronger patent protection as even more important for knowledge with roots in open science. This finding provides empirical evidence of firms' efforts to create private knowledge from public knowledge (e.g., Cockburn & Henderson, 1998; Cohen & Levinthal, 1990; Fleming & Sorenson, 2004; Powell et al., 1996). Given that inventions building on open science are likely to create value for a longer period of time, managers can deploy multi-layered strategies to develop inventions drawing on open science and secure/maintain strong property rights on them in order to enhance value appropriation from innovation.

My study could be improved in several ways. Although I examine firms' *purchase* of options to extend patent term, I do not examine their *exercise* of these options. In my empirical context, the "nominal" exercise happens when a patent has issued. If the patent issued within three years of the earliest filing date, the patentee would receive patent term extension as the new 20-year rule permits. If the patent issued after three years of the earliest filing date, the patentee would receive patent term extension as the old 17-year rule permits. However, the "actual" exercise will happen when the patentee pays a renewal fee at 11.5 years from issuance in order to keep the patent in force for the full patent term. Future research can explore how firms' filing of patents immediately before the transition (i.e., the purchase of options) is correlated with their decision to renew these patents (i.e., the exercise of options), which will provide a richer description of how firms' real options reasoning in patenting strategies plays out over time. Another avenue for future research is to study how firms' purchase of options in patent term extension covaries with the patent's other post-grant attributes such as litigation, licensing, and ownership transfers. Investigating these various strategies with respect to a patent will be interesting since it will capture how a firm's actions evolve with respect to the patent (Somaya, 2012).

In summary, this study examines firms' revealed preference to file a patent immediately before (relative to after) the U.S. patent term transition ushered in by TRIPS. I view this choice as firms' purchase of options to extend patent term and find that the choice is impacted by various invention attributes. My study contributes to the literature in IP and appropriability strategies and in particular, real options in innovation.

TABLES AND FIGURE

Table 4.1: Summary statistics and correlations for variables

	Variable	Mean	Std. Dev.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)	Before TRIPS (dummy)	0.848	0.359	0.000	1.000	1.000												
(2)	Expected prosecution time	781.797	94.996	664.048	895.682	0.149	1.000											
(3)	Patent prosecution uncertainty	456.329	238.455	1.584	1750.584	0.145	0.279	1.000										
(4)	Continuing application (dummy)	0.613	0.487	0.000	1.000	0.367	0.187	0.171	1.000									
(5)	Continuation (dummy)	0.180	0.384	0.000	1.000	0.114	0.110	0.028	0.370	1.000								
(6)	Continuation-in-part (dummy)	0.156	0.363	0.000	1.000	0.094	0.076	0.159	0.338	-0.202	1.000							
(7)	Divisional (dummy)	0.277	0.447	0.000	1.000	0.225	0.043	0.031	0.473	-0.290	-0.266	1.000						
(8)	Priority lapse	885.826	1019.064	0.000	14924.000	0.233	0.184	0.212	0.567	0.280	0.113	0.285	1.000					
(9)	No. forward citations	113.678	194.741	0.000	4908.000	0.015	0.098	-0.072	-0.030	-0.007	0.040	-0.050	-0.081	1.000				
(10)	No. backward citations	18.818	32.360	0.000	800.000	0.090	-0.005	0.076	0.133	0.006	0.118	0.047	0.126	0.073	1.000			
(11)	Proportion. self-citations	0.118	0.221	0.000	1.000	0.040	0.019	-0.003	0.069	0.017	-0.007	0.071	0.091	-0.037	-0.071	1.000		
(12)	No. backward non-patent citations	10.304	29.296	0.000	787.000	0.124	0.220	0.270	0.189	0.042	0.154	0.042	0.244	-0.008	0.333	-0.036	1.000	
(13)	Invention breadth	1.501	0.646	0.000	3.000	0.120	0.079	0.214	0.198	0.023	0.099	0.113	0.203	-0.043	0.080	0.027	0.206	1.000

Table 4.2: Logit models for firms' choice to file before the new 20-year rule (with technology category dummies)

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Marginal effects
Chemical (dummy)	0.3575***	0.3436***	0.3420***	0.2376**	0.2231**	0.0134**
	(0.0936)	(0.0950)	(0.0953)	(0.0967)	(0.0969)	(0.0059)
Computers & Communications (dummy)	0.1214	0.1456	0.1492	0.0941	0.0998	0.0060
	(0.1132)	(0.1143)	(0.1150)	(0.1141)	(0.1144)	(0.0068)
Drugs & Medical (dummy)	1.2543***	1.2849***	1.2722***	0.9482***	0.9418***	0.0566***
	(0.1138)	(0.1144)	(0.1149)	(0.1221)	(0.1220)	(0.0084)
Electrical & Electronic (dummy)	0.0827	0.0833	0.0859	0.0776	0.0799	0.0048
	(0.0996)	(0.1007)	(0.1012)	(0.1006)	(0.1010)	(0.0060)
Others (dummy)	-0.0074	0.0104	0.0104	-0.0112	-0.0178	-0.0011
	(0.0963)	(0.0963)	(0.0960)	(0.0947)	(0.0950)	(0.0057)
Continuing application (dummy)	2.1329***	0.9968***	0.9476***	0.9514***	0.9471***	0.0569***
	(0.0805)	(0.1850)	(0.1816)	(0.1880)	(0.1883)	(0.0118)
Continuation (dummy)		0.7627***	0.6558***	0.5413**	0.5505***	0.0331**
		(0.2130)	(0.2024)	(0.2123)	(0.2123)	(0.0128)
Continuation-in-part (dummy)		0.7621***	0.6955***	0.3981*	0.3994*	0.0240*
		(0.2099)	(0.1983)	(0.2070)	(0.2070)	(0.0126)
Divisional (dummy)		1.9097***	1.8244***	1.7220***	1.7235***	0.1035***
		(0.2056)	(0.1980)	(0.2110)	(0.2113)	(0.0130)
Priority lapse			0.0001**	0.0001*	0.0001*	0.0000*
			(0.0001)	(0.0001)	(0.0001)	(0.0000)
No. forward patent citations				0.0003**	0.0003**	0.0000**
				(0.0001)	(0.0001)	(0.0000)
No. backward patent citations				0.0119***	0.0119***	0.0007***
				(0.0024)	(0.0024)	(0.0001)
Proportion. self-citations				0.1295	0.1247	0.0075
				(0.1410)	(0.1411)	(0.0084)
No. backward non-patent citations				0.0342***	0.0334***	0.0020***
				(0.0069)	(0.0069)	(0.0003)
Invention breadth					0.0886**	0.0053**
					(0.0437)	(0.0027)
Constant	0.5918***	0.5695***	0.5462***	0.3285***	0.2172**	
	(0.0763)	(0.0767)	(0.0767)	(0.0836)	(0.0976)	
No. obs.	21,535	21,535	21,500	20,408	20,408	20,408

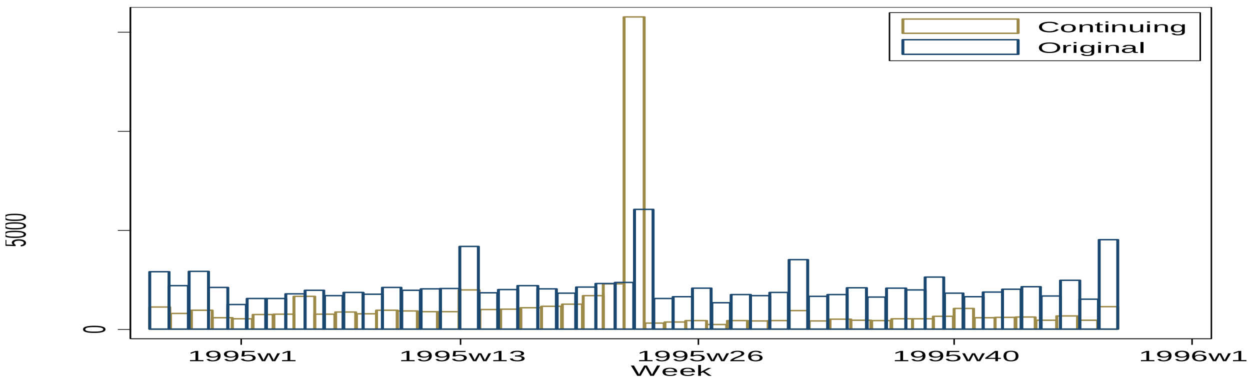
Clustered standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; Reference category: mechanical

Table 4.3: Logit models for firms' choice to file before the new 20-year rule (with patent prosecution variables)

Variables	Model (6)	Model(7)	Model (8)	Model (9)	Model (10)	Model (11)	Model (12)	Marginal effects
Continuing application (dummy)	2.2408***	2.2030***	1.1491***	1.0997***	1.0997***	1.0839***	1.0728***	0.0644***
	(0.0763)	(0.0776)	(0.1890)	(0.1834)	(0.1834)	(0.1918)	(0.1921)	(0.0122)
Expected prosecution time	0.0025***	0.0019***	0.0020***	0.0020***	0.0020***	0.0013***	0.0013***	0.0001***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0000)
Patent prosecution uncertainty		0.0010***	0.0010***	0.0010***	0.0010***	0.0005***	0.0005***	0.0000***
		(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0000)
Continuation (dummy)			0.6354***	0.5142**	0.5142**	0.4059*	0.4217**	0.0253**
			(0.2122)	(0.2021)	(0.2021)	(0.2138)	(0.2138)	(0.0128)
Continuation-in-part (dummy)			0.6990***	0.6251***	0.6251***	0.3276	0.3335	0.0200
			(0.2126)	(0.2002)	(0.2002)	(0.2099)	(0.2097)	(0.0127)
Divisional (dummy)			1.8314***	1.7349***	1.7349***	1.6322***	1.6367***	0.0982***
			(0.2036)	(0.1959)	(0.1959)	(0.2119)	(0.2122)	(0.0131)
Priority lapse				0.0001***	0.0001***	0.0001**	0.0001*	0.0000*
				(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0000)
No. forward patent citations						0.0002	0.0002	0.0000
						(0.0002)	(0.0002)	(0.0000)
No. backward patent citations						0.0109***	0.0109***	0.0007***
						(0.0024)	(0.0024)	(0.0001)
Proportion. self-citations						0.1478	0.1399	0.0084
						(0.1415)	(0.1414)	(0.0085)
No. backward non-patent citations						0.0422***	0.0411***	0.0025***
						(0.0073)	(0.0073)	(0.0003)
Invention breadth							0.1042**	0.0063**
							(0.0442)	(0.0027)
Constant	-1.0466***	-0.9972***	-1.0884***	-1.0897***	-1.0897***	-0.6894**	-0.8434***	
	(0.2702)	(0.2650)	(0.2637)	(0.2626)	(0.2626)	(0.2718)	(0.2774)	
No. obs.	21,535	21,492	21,492	21,457	21,457	20,366	20,366	20,366

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 4.1: Number of patent applications filed each week during 12/01/1994-12/08/1995



N.B. The TRIPS effective date June 8, 1995 is in the 23rd week of 1995 (1995w23 in this graph).

CHAPTER 5: CONCLUSION

In my dissertation, I highlight what drives firms to purchase real options to preserve flexibility in their patenting strategies. Examining firms' use of real options reasoning is important because firms need to deal with significant *ex ante* uncertainties in making costly patenting decisions in the innovation landscape. Although real options theory has substantially informed firms' decision-making in value creation through innovation (e.g., Hurry et al., 1992; Mitchel & Hamilton, 1988; McGrath, 1997; McGrath & Nerkar, 2004), how firms can use real options to appropriate value from innovation remains relatively understudied. This gap in the literature is surprising given that value appropriation is an important goal of firms' innovation strategy (e.g., Lepak et al., 2007; Nordhaus, 1969; Scherer, 1965; Teece, 1986). My dissertation contributes to the existing literature by examining how real options provide firms with an ability to deal with critical strategic commitment problems under uncertainties in making the value appropriation decisions of how to protect their innovations against rivals.

In my first empirical study (chapter two), I examine what drives firms to purchase real options and delay the time of deciding on the mutually exclusive appropriability mechanisms of patenting and secrecy. By doing so, firms can potentially make a better choice of the appropriability mechanism for the protection of their inventions, benefiting from the resolution of uncertainties. In my second empirical study (chapter three), I examine what drives firms to purchase real options and mitigate the patent racing challenges of time compression diseconomies (e.g., Dierickx & Cool, 1989). In my third empirical study (chapter four), I investigate how firms can purchase real options and choose between a shorter and a longer patent term. By doing so, firms can appropriate value from inventions, which vary in their characteristics, however long they want as they go forward in time within the bounds provided by the patent system. Thus, my dissertation takes the problem-solving perspective (e.g., Nickerson & Zenger, 2004) and proposes that the purchase of real options in patenting strategies takes place as a solution to deal with distinct appropriability problems. Furthermore, my dissertation assesses the value of real options at the granular, invention level and thus answers calls by recent work in strategic management (Trigeorgis & Reuer, 2017). Methodologically, I leverage three different changes in U.S. patent law and robustly deal with potential endogeneity concerns for the antecedents of firms' purchase of real options. I believe that my dissertation opens the door to further research on real options in appropriability strategies.

In chapter two, I examine the firms' use of "secrecy options", which I define as choices whereby firms put a stake in the ground for patent protection while preserving the right to withdraw from the patenting process without affecting their ability to retain secrecy of technologies. I propose that the higher the risk of technology disclosure to rivals, the greater the value of secrecy options in the initial acquisition of the patent right. Empirically, I leverage the enactment of the American Inventors Protection Act and firms' use of provisional patent applications, and show that patent applicants exposed to faster disclosure of technologies were more likely to purchase secrecy options. Strikingly, the filing of a provisional increased by 45.8% after AIPA went into effect. Moreover, I find that the value of secrecy options in response to faster disclosure was greater for smaller firms, consistent with prior research on knowledge misappropriation (e.g., Dushnitsky & Lenox, 2005; Katila et al., 2008) and IP strategies (e.g., Arundel, 2001; Sichelman & Graham, 2010). I also find that the value of secrecy options in response to faster disclosure was greater for more novel technologies, consistent with real options theory (e.g., Dixit & Pindyck, 1994; Smit & Trigeorgis, 2004).

In chapter three, I examine firms' use of "patenting real options". I propose that patenting real options are more valuable under a first-to-file (FTF) than a first-to-invent (FTI) system. Empirically, I leverage U.S. transition from a FTI to a FTF system, implemented by the America Invents Act, and show that firms were 25% more likely to file provisional applications (relative to regular applications) as solutions to the incentives and challenges imposed by a FTF system. Furthermore, my contingency findings shed light on the strategic implications of the winner-take-all features of patent systems (e.g., Gilbert & Newbery, 1982; Reinganum, 1983; Tirole, 1989). I find that the strategies of all firms are not identical, and the use of provisional applications in response to the implementation of a FTF system depends on technological dominance, market concentration, and patent effectiveness.

In chapter four, I examine firms' revealed preference to preserve a longer patent term, which varies in many invention attributes. Empirically, I leverage U.S. transition from the 17-years-from-issuance to the 20-years-from-filing patent term, implemented by the TRIPS agreement, which also offered the two discrete choices of either patent term to patentees that filed patents during the interim period between the enactment and the effective date. I find that firms were more likely to use these options by filing before (relative to after) the TRIPS effective date when they expect greater uncertainties in patent prosecution for their inventions, consistent with real options theory. Furthermore, I find that real options in patent term extension were more valuable for inventions in industries with slow technology pace and inventions that are potentially more valuable.

My dissertation contributes to the appropriability strategies literature by examining how firms may use real options reasoning to preserve future decision rights in their patenting strategies in the presence of significant uncertainties. In chapter two, I show that firms seek to make the patent-secrecy tradeoff dynamically overtime by purchasing real options while patenting. In chapter three, I show that firms seek to gain a foothold in patent protection swiftly under a FTF system by purchasing real options and decide at a later time whether to continue with securing the patent right when patent uncertainties are resolved. In chapter four, I show that firms seek to preserve a longer patent term for their inventions by using real options provided by a unique legal setting in order to deal with patent prosecution uncertainties. My dissertation studies how firms manage inherent uncertainties – technological, commercial, and/or legal – in the patent right and thus answers calls by recent work on patent strategies (Somaya, 2012).

Furthermore, my dissertation contributes to the real options literature by empirically testing for received theory in a new context. Although real options theory greatly informed various managerial decisions (e.g., Dixit & Pindyck, 1994; Folta & Miller, 2002; Kogut, 1991; Kulatilaka & Perotti, 1998; Li et al., 2007; McDonald & Siegel, 1986; Smit & Trigeorgis, 2004; Teece, 1992; Trigeorgis & Reuer, 2017) and value-creating innovation decisions (e.g., Hurry, Miller, & Bowman, 1992; Mitchel & Hamilton, 1987; McGrath, 1997; McGrath & Nerkar, 2004), a dearth of research persists on how firms can use real options reasoning to appropriate value from inventions, which is an important goal of innovation (Lepak et al., 2007; Nordhaus, 1969; Scherer, 1965; Teece, 1986). My dissertation sheds light on firms' use of real options for the protection of inventions against others. Empirically, I assess the value of real options at the granular, invention level, as called for by recent work as a potentially fruitful approach to real option valuation (Trigeorgis & Reuer, 2017), and thus make further empirical contributions to the real options literature.

The findings of my dissertation have important implications for management. Especially, the examined conditions under which the real options on patents are more valuable provide managers with insights on when to keep options open in their attempts to appropriate value from innovation. The specific phenomenon of provisional patent applications, used as a proxy for real options on patents, sheds light on potential ways in which managers can keep options open in deploying appropriability strategies. While my dissertation shows how firms can deal with uncertainties patenting entails in the initial acquisition of the patent right, these uncertainties may also pervade the other domains of patent strategy (Somaya, 2012), such as licensing, and enforcement and litigation. Examining firms' use of real options in these domains of patent strategy will be a potentially fruitful avenue for future research, complementing the empirical studies of my dissertation.

Finally, my dissertation examines how firms' patenting strategies interact with changes in U.S. patent law and has important implications for policy. The findings of my dissertation suggest that firms reacted to legislative changes by changing their patenting behavior promptly. In chapter two, we have seen how firms may use provisional patent applications to hedge their bets between patents and secrecy for the protection of the same invention, which may potentially counteract the patent system's grand goal of promoting the early dissemination of knowledge (Mazzoleni & Nelson, 1998). In chapter three, we have seen that provisional patent applications can be used by large firms with greater downstream market power to preempt others from obtaining patents on their inventions. This finding may potentially inform policymakers who are concerned about anticompetitive firm behavior. In chapter four, the invention attributes which affect firms' preferences to obtain a longer patent term inform policymakers hoping to incentivize innovation for who may be interested in obtaining (and arguably deserve) a longer patent term than others.

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APPENDIX A:

CHAPTER TWO SUPPLEMENTARY MATERIALS

Table A.1: Linear probability model for use of a provisional with assignee fixed effects

	Full sample	Non-Compustat subsample	Compustat subsample
Post-AIPA	0.0118***	0.0114***	0.0164**
	(0.0039)	(0.0041)	(0.0074)
Domestic protection	0.0075	0.0072	0.0121
	(0.0068)	(0.0086)	(0.0098)
Post-AIPA * Domestic protection	0.0164	0.0526***	-0.0057
	(0.0100)	(0.0143)	(0.0128)
No. forward citations	0.0011	0.0010	0.0013
	(0.0008)	(0.0012)	(0.0012)
Post-AIPA * No. forward citations	0.0020	0.0003	0.0032
	(0.0014)	(0.0018)	(0.0021)
Domestic protection * No. forward citations	0.0013	0.0019	0.0007
	(0.0012)	(0.0021)	(0.0016)
Post-AIPA * Domestic protection * No. forward citations	-0.0003	0.0008	-0.0008
	(0.0024)	(0.0035)	(0.0031)
No. claims	0.0006***	0.0007***	0.0005***
	(0.0001)	(0.0001)	(0.0002)
Post-AIPA * No. claims	0.0000	-0.0002	0.0001
	(0.0002)	(0.0002)	(0.0002)
Domestic protection * No. claims	-0.0007***	-0.0013***	-0.0005
	(0.0002)	(0.0003)	(0.0003)
Post-AIPA * Domestic protection * No. claims	-0.0003	-0.0000	-0.0003
	(0.0003)	(0.0005)	(0.0004)
No. backward citations	0.0009***	0.0004*	0.0013***
	(0.0002)	(0.0002)	(0.0003)
Post-AIPA * No. backward citations	-0.0002	0.0002	-0.0006
	(0.0003)	(0.0003)	(0.0005)
Domestic protection * No. backward citations	-0.0007***	-0.0002	-0.0013***
	(0.0003)	(0.0004)	(0.0004)
Post-AIPA * Domestic protection * No. backward citations	0.0001	-0.0006	0.0008
	(0.0004)	(0.0005)	(0.0006)
Constant	0.0643***	0.0682***	0.0579***
	(0.0034)	(0.0036)	(0.0064)
Technology category dummies	Yes	Yes	Yes
Assignee fixed effects	Yes	Yes	Yes
Observations	216,500	126,034	90,466

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Technology category dummies included, with mechanical as the reference category.

APPENDIX B:

CHAPTER THREE SUPPLEMENTARY MATERIALS

Table B.1: AIA effective dates

Date of Enactment *September 16, 2011*	1 Year from Enactment *September 16, 2012*	18 Months from Enactment *March 16, 2013*
• Prior User Rights - §5 Patents issued on or after this date • Post Grant Review - §6 New Inter Partes Reexam Standard Ex Parte Appeals Eliminated • Fees - §11 • Tax Strategies - §14 • Best Mode - §15 Suits started on or after this date • Marking - §16 False Marking Virtual Marking • Jurisdiction and Procedural - §19 • USPTO Funding - §22	• General Effective Date - §35 • Oath or Declaration - §4 • Post Grant Review Procedures - §6 New Opposition Proceeding New Inter Partes Review • Third Party Submissions - §8 • Supplemental Examination - §12 • Business Method Patent Review - §18	• First Inventor to File - §3 New §§102 and 103 apply

Source: American Intellectual Property Law Association (AIPLA) (http://www.aipla.org/advocacy/congress/aia/Pages/The-Act.aspx)

Table B.2: Economic significance of three-way interaction in Table 3.4

	Full sample	Large entity subsample
Model (5; product)		
Industry concentration	0.00811	0.01345
Patent effectiveness	-0.02631	-0.04128
Technological dominance	-0.01402	-0.01062
Model (5; process)		
Industry concentration	0.00407	0.00492
Patent effectiveness	-0.04001	-0.06955
Technological dominance	-0.01872	-0.01476

Table B.3: Linear probability model for use of a provisional with assignee fixed effects

	Full sample	Small entity subsample	Large entity subsample
Post-AIA	-0.0000	0.0163	-0.0026
	(0.0044)	(0.0124)	(0.0047)
Domestic protection	0.0485	0.1674***	0.0470
	(0.0380)	(0.0314)	(0.0492)
Post-AIA * Domestic protection	0.0742*	0.0416	0.0858
	(0.0438)	(0.0318)	(0.0573)
No. forward citations	0.0043***	-0.0011	0.0046***
	(0.0012)	(0.0029)	(0.0013)
Post-AIA * No. forward citations	-0.0039**	0.0014	-0.0042***
	(0.0015)	(0.0039)	(0.0016)
Domestic protection * No. forward citations	-0.0069***	-0.0015	-0.0067***
	(0.0023)	(0.0075)	(0.0024)
Post-AIA * Domestic protection * No. forward citations	0.0049*	-0.0109	0.0062**
	(0.0026)	(0.0090)	(0.0027)
No. claims	0.0002	-0.0016***	0.0007***
	(0.0002)	(0.0004)	(0.0002)
Post-AIA * No. claims	0.0015***	0.0002	0.0017***
	(0.0002)	(0.0006)	(0.0002)
Domestic protection * No. claims	-0.0004	0.0026***	-0.0013
	(0.0013)	(0.0009)	(0.0018)
Post-AIA * Domestic protection * No. claims	-0.0018	0.0023*	-0.0030
	(0.0017)	(0.0014)	(0.0023)
No. backward citations	0.0000	-0.0001	0.0000
	(0.0000)	(0.0001)	(0.0000)
Post-AIA * No. backward citations	-0.0003***	-0.0001	-0.0003***
	(0.0001)	(0.0003)	(0.0001)
Domestic protection * No. backward citations	-0.0001	-0.0006**	-0.0000
	(0.0001)	(0.0003)	(0.0001)
Post-AIA * Domestic protection * No. backward citations	-0.0004*	-0.0011*	-0.0003
	(0.0002)	(0.0006)	(0.0002)
Constant	0.1106***	0.2105***	0.0895***
	(0.0072)	(0.0160)	(0.0074)
Technology category dummies	Yes	Yes	Yes
Assignee fixed effects	Yes	Yes	Yes
No. obs.	265,582	34,033	231,549

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Technology category dummies included, with mechanical as the reference category.

APPENDIX C:

CHAPTER FOUR SUPPLEMENTARY MATERIALS

Table C.1: Logit models for firms' choice to file before the new 20-year rule

Variables	Model (13)	Model (14)	Model (15)	Model (16)	Model (17)	Model (18)	Model (19)
Chemical (dummy)	0.3575***	0.2769***	0.2629***	0.1410	0.1410	0.1066	0.0811
	(0.0936)	(0.0939)	(0.0952)	(0.1249)	(0.1249)	(0.1246)	(0.1257)
Computers & Communications (dummy)	0.1214	0.0513	0.0761	0.0433	0.0433	0.0373	0.0458
	(0.1132)	(0.1139)	(0.1147)	(0.1502)	(0.1502)	(0.1508)	(0.1510)
Drugs & Medical (dummy)	1.2543***	1.0959***	1.1260***	0.8808***	0.8808***	0.6892***	0.6756***
	(0.1138)	(0.1150)	(0.1152)	(0.1490)	(0.1490)	(0.1580)	(0.1580)
Electrical & Electronic (dummy)	0.0827	0.0694	0.0715	0.0299	0.0299	0.0204	0.0191
	(0.0996)	(0.0996)	(0.1007)	(0.1293)	(0.1293)	(0.1282)	(0.1299)
Others (dummy)	-0.0074	-0.0326	-0.0126	-0.1396	-0.1396	-0.1192	-0.1386
	(0.0963)	(0.0967)	(0.0968)	(0.1358)	(0.1358)	(0.1323)	(0.1331)
Continuing application (dummy)	2.1329***	2.1212***	0.9773***	1.1085***	1.1085***	1.1239***	1.1134***
	(0.0805)	(0.0813)	(0.1986)	(0.2018)	(0.2018)	(0.1933)	(0.1929)
Patent prosecution uncertainty		0.0007***	0.0008***	0.0007***	0.0007***	0.0004***	0.0004***
		(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Continuation (dummy)			0.7725***	1.0052***	1.0052***	0.8554***	0.8754***
			(0.2253)	(0.2223)	(0.2223)	(0.2202)	(0.2197)
Continuation-in-part (dummy)			0.7361***	1.0142***	1.0142***	0.7267***	0.7378***
			(0.2233)	(0.2212)	(0.2212)	(0.2179)	(0.2170)
Divisional (dummy)			1.9195***	2.1638***	2.1638***	2.0308***	2.0386***
			(0.2175)	(0.2167)	(0.2167)	(0.2200)	(0.2202)
Priority lapse (logged)				0.0321	0.0321	0.0204	0.0143
				(0.0577)	(0.0577)	(0.0611)	(0.0609)
No. forward patent citations						0.0004*	0.0004*
						(0.0002)	(0.0002)
No. backward patent citations						0.0069***	0.0067***
						(0.0024)	(0.0024)
Proportion. self-citations						0.2706*	0.2643*
						(0.1592)	(0.1596)
No. backward non-patent citations						0.0260***	0.0245***
						(0.0079)	(0.0078)
Invention breadth							0.1586***

Table C.1 (continued)

							(0.0531)
Constant	0.5918***	0.3412***	0.3161***	-0.1421	-0.1421	-0.1560	-0.3185
	(0.0763)	(0.0875)	(0.0880)	(0.3851)	(0.3851)	(0.3977)	(0.4033)
No. obs.	21,535	21,492	21,492	16,849	16,849	15,898	15,898

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Reference category: mechanical

Table C.2: Logit models for firms' choice to file before the new 20-year rule (split subsample analyses for original and continuing applications)

Variables	Original subsample	Original subsample	Original subsample	Continuing subsample	Continuing subsample	Continuing subsample	Continuing subsample
Chemical (dummy)	0.2214**	0.1438	0.1471	0.4131**	0.3766**	0.3067*	0.3114*
	(0.1090)	(0.1121)	(0.1126)	(0.1700)	(0.1740)	(0.1739)	(0.1779)
Computers & Communications (dummy)	0.0596	0.0105	0.0090	0.0684	0.1146	0.1727	0.2710
	(0.1271)	(0.1284)	(0.1282)	(0.1960)	(0.1970)	(0.1971)	(0.1942)
Drugs & Medical (dummy)	1.0348***	0.7581***	0.7587***	1.2063***	1.0590***	1.0161***	1.0381***
	(0.1342)	(0.1388)	(0.1389)	(0.2012)	(0.2237)	(0.2217)	(0.2237)
Electrical & Electronic (dummy)	0.0666	0.0567	0.0561	0.0932	0.1465	0.1798	0.2073
	(0.1138)	(0.1140)	(0.1138)	(0.1811)	(0.1824)	(0.1856)	(0.1869)
Others (dummy)	-0.0125	-0.0427	-0.0413	-0.1040	-0.0844	-0.1236	0.0032
	(0.1086)	(0.1077)	(0.1079)	(0.1905)	(0.1874)	(0.1873)	(0.1901)
Patent prosecution uncertainty	0.0006***	0.0002*	0.0003*	0.0013***	0.0009***	0.0008***	0.0009***
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
No. forward patent citations		0.0004**	0.0004**		-0.0002	-0.0002	0.0002
		(0.0002)	(0.0002)		(0.0002)	(0.0002)	(0.0003)
No. backward patent citations		0.0130***	0.0130***		0.0107***	0.0101***	0.0088***
		(0.0034)	(0.0034)		(0.0032)	(0.0031)	(0.0030)
Proportion. self-citations		0.0653	0.0674		0.4547**	0.4454*	0.3039
		(0.1636)	(0.1637)		(0.2290)	(0.2296)	(0.2295)
No. backward non-patent citations		0.0417***	0.0419***		0.0197**	0.0169**	0.0187**
		(0.0098)	(0.0099)		(0.0083)	(0.0079)	(0.0082)
Invention breadth			-0.0228			0.4326***	0.3489***
			(0.0513)			(0.0858)	(0.0896)
Continuation (dummy)							-0.4969
							(0.7404)
Continuation-in-part (dummy)							-0.4627
							(0.7404)
Divisional (dummy)							0.7535
							(0.7442)
Priority lapse (logged)							0.4330***
							(0.0564)
Constant	0.4227***	0.2918***	0.3200***	2.2073***	1.9979***	1.4591***	-1.3668
	(0.0967)	(0.1070)	(0.1237)	(0.1618)	(0.1789)	(0.2074)	(0.8369)

Table C.2 (continued)

No. obs.	7,851	7,533	7,533	13,641	12,865	12,865	12,836

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Reference category: mechanical